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**REPORTS OF THE EXPERT CONSULTATION
TO EXAMINE CHANGES IN ABUNDANCE
AND SPECIES COMPOSITION
OF NERITIC FISH RESOURCES**



FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

REPORTS OF THE EXPERT CONSULTATION
TO EXAMINE CHANGES IN ABUNDANCE AND SPECIES
COMPOSITION OF NERITIC FISH RESOURCES

San José, Costa Rica
18-29 April 1983

Edited by

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Fisheries Department

A preparatory meeting for the FAO World Conference on
Fisheries Management and Development

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PREPARATION OF THIS DOCUMENT

This volume consists of the Reports of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources held in San José, Costa Rica, 18-29 April 1983. The Proceedings, containing the technical contributions produced for, and presented and discussed at, the Expert Consultation are published in Volumes 2 and 3 of this FAO Fisheries Report No. 291.

This volume contains a brief account of the Expert Consultation, followed by the reports of the four working groups which met during the consultation and were responsible for extracting the main results, conclusions and recommendations of the meeting. Collectively these constitute the Report of the Expert Consultation. Each working group produced a draft report during the consultation which, together with comments and suggestions made at the plenary session on the last day, were the basis on which the chairman of each working group prepared the final versions presented here.

This document was reviewed and edited by Drs. J. Csirke and G.D. Sharp*, Technical Secretaries of the Expert Consultation. Ms. D. Dearing was responsible for the bulk of the typing and preparation of this volume, assisted by Mrs. Y. Corsetti.

This Expert Consultation was one of the preparatory meetings for the FAO World Conference on Fisheries Management and Development. The consultation was organised by FAO with the support of IOC, CPPS, DANIDA, ICLARM, ICSEAF, IDB, SELA, Unesco and WMO.

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ABSTRACT

There is a high degree of uncertainty in dealing with varying neritic fish resources. It is difficult to establish national development policies based on contributions from an unstable fishing sector and long-term objectives can hardly be achieved unless a management strategy can be developed to cope with this variability. More flexibility needs to be introduced in the fishery sector to allow its adaptation to resource changes, and these and the causal environmental processes need to be properly monitored. Some of the problems and alternatives associated with exploitation, research and management of fluctuating fisheries are discussed.

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P A R T I

THE EXPERT CONSULTATION

1. OPENING OF THE SESSIONS

The Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources was held in San José, Costa Rica, 18-29 April 1983. The sessions were attended by fifty-eight participants from eighteen countries and various regional and international organizations. A list of participants is given in Appendix 1. All participants attended the Expert Consultation in a personal capacity.

The opening ceremony was chaired by the Minister of Agriculture and Livestock of the Government of Costa Rica, Mr. Francisco Morales Hernandez, who inaugurated the Consultation and gave the opening speech on behalf of the host country. Dr. Armin H. Lindquist, Director of the Fishery Resources and Environment Division, FAO, gave the opening speech on behalf of the Director-General of FAO.

2. BACKGROUND OF THE EXPERT CONSULTATION

This Expert Consultation was one of the preparatory meetings for the FAO World Conference on Fisheries Management and Development, and was also a contribution to the Programme on Ocean Sciences in Relation to Living Resources adopted by the Intergovernmental Oceanographic Commission.

The Expert Consultation was organised by FAO with the support of: Intergovernmental Oceanographic Commission (IOC), Permanent Commission for the South Pacific (CPPS), Danish International Development Agency (DANIDA), International Center for Living Aquatic Resources Management (ICLARM), International Commission for the South East Atlantic Fisheries (ICSEAF), Inter-American Development Bank (IDB), Action Committee for Seafood and Freshwater Products of the Latin American Economic System (SELA), United Nations Educational, Scientific and Cultural Organization (Unesco) and World Meteorological Organization (WMO).

It is unlikely that such a collection of experts, most of them involved in basic and applied research relevant to the problems of fishery and related environmental sciences, and others involved in management, social and economical aspects of fisheries, could have been convened at a more appropriate time. The 1982-83 "El Niño" phenomenon was in full stride while the consultation was taking place, thus reinforcing everyone's concern about environmentally-induced resource fluctuations, and the need to understand and forecast these types of event.

Floods in Ecuador, northern Peru, Polynesia and U.S.A.; droughts in Indonesia, Philippines, Australia, New Guinea, Africa, southern India and southern China; unprecedented changes in fish populations throughout the Pacific basin and in seabird populations together with their stress-induced behaviour all became front-page news around the world. What had been considered a local phenomenon mainly affecting living marine resources off the northwestern coasts of South America became generally recognised for what it really is: an atmospheric-ocean phenomenon in the eastern equatorial Pacific, linked to major global-scale climatic perturbations, which affects the lives of many people throughout the Pacific basin and elsewhere around the world.

The latest "El Niño" phenomenon and other recent events which have affected the climate and biological production over extensive areas in the Atlantic and the Pacific Oceans have had a remarkable impact on the views of many fishery scientists and fishery administrations with regard to neritic fish resources, what to expect from them, how to investigate and monitor their fluctuations, and how to effectively manage their fisheries.

New concepts and alternative methods are needed to properly deal with fisheries and fishery resources which are highly variable, clearly affected by environmental changes, and for which the conventional fishery monitoring systems and available measuring techniques can only provide short-term and limited space-scale forecasts, which result in a reduced number of possible management options usually limited to very short-term reactions.

Why do neritic fish resources vary? What is the role played by the environment in these fluctuations? What is the role of fishing? How intra- and inter-specific relations affect the stability of neritic fish resources? What are the short- and long-term effects of these fluctuations? What should be done to enable timely detection of major environmentally-induced changes in neritic fish resources? And, if major resource changes are imminent, what could fisheries management do to prevent failure of the fishery and its impact on the national economy and society? These are just some of the leading questions that motivated FAO to organise and convene this Expert Consultation.

This meeting was also a timely follow-up to the many related regional or topical symposia, workshops and research programmes which had been channeling the attention of the scientific community toward a more comprehensive approach to fishery sciences, particularly to fish resources variability, its causes and consequences. Some scientific events which more directly influenced this consultation were: Symposium of the International Council for the Exploration of the Sea (ICES) on the Assessment and Management of Pelagic Fish Stocks, held in Aberdeen in 1978 (Saville, 1980); analytical phase of the joint Canadian-Peruvian ICANE (Investigación Cooperativa de la Anchoveta y su Ecosistema) research project which culminated with a scientific workshop held in Callao in November 1979 (IMARPE, 1981); FAO Workshop on the Effects of Environmental Variation on the Survival of Larval Pelagic Fishes, held in Callao in 1980 (Sharp, 1981); and IOC Resolutions XI-17 and XII-1, adopted in Paris in 1979 and 1982 (IOC, 1980 and 1983), which provided the stimulus for giving appropriate consideration to the topic of Ocean Sciences in Relations to Living Resources (OSLR) in the international context.

At an early stage in the preparations for this Expert Consultation it became clear that a multidisciplinary approach was essential in order to properly address the problems of highly variable fish resources. There was a need to assemble the experiences gained in several important neritic fisheries of the world and to cover several fields of interest ranging from fishery biology to resource evaluation, fishery management, oceanography, meteorology, sociology, economy, industry and finance; and this was one of the main criteria for choosing most of the participants in this consultation. After selecting such an heterogeneous and highly specialised group of experts, it was encouraging to note that there was no problem whatsoever in communication during the consultation, facilitating an easy and very active exchange of experiences which it is hoped will continue. The impossibility of having more of the front-line fishery researchers and managers was regretted, but facilities and time were limited. In any case it was felt that the fisheries community would appreciate the efforts of those who had the opportunity to contribute in extending our knowledge and abilities to measure, monitor and assess the impacts of the various system perturbations on fishery resources and, thus, on human activities.

3. OBJECTIVES OF THE CONSULTATION

The central theme of the consultation was the variability of neritic fish resources; their changes in abundance, species composition, distribution, behaviour, productivity, etc.; their causes and impacts on fishery and fishery related human activities. The specific objectives of the consultation were:

- to document the changes that have occurred in each region, in the environment, in the abundance and distribution of fish populations, and in the fisheries, including societal and economic effects;
- to identify the objectives of decision-makers and document how these were affected by changes in fish resources;
- to provide an opportunity for comparison between regions, and to establish the similarities and differences, as a basis for improved understanding of the events in each individual region;

- to promote the inter-disciplinary study of the neritic systems, bringing together experts in the fields of oceanography and meteorology, basic biology, fishing industry, resource assessment and monitoring, and fishery management;

- to increase the understanding of the general processes involved in the dynamics of neritic fisheries, which might lead to improved ability to predict significant changes in the system, hence allowing more time and options for the decision-making process;

- to provide a better scientific basis for the development of a management strategy which would take account of the best current knowledge as well as the possibility of large-scale changes in the natural system.

4. ORGANIZATION

The Expert Consultation took place in two phases: the first week was characterised by symposium-type sessions where individual background and review papers were presented and discussed; and the second week consisted of working sessions of four working groups set up to review and discuss specific topics and to produce the draft versions of the four reports of the Expert Consultation presented in this volume. The agenda and timetable of these two-week sessions are given in Appendix 2.

The introduction to the first week of technical presentations was made by J. Csirke and G.D. Sharp, FAO Fishery Resources Officers and Technical Secretaries of the consultation. This included a global review of the scale and magnitude of landing variations of major neritic fisheries of the world, as well as some overall views of symptoms and responses of changing ecosystems. This was followed by individual presentations and discussion of fifty-three papers and by an informal round-table discussion on objectives of fishery management and decision-making processes. This informal round-table was chaired by M.H. Glantz and comprised various interest groups available among the participants, i.e. industry scientists, international investment bank representatives, fishery managers, multinational fish buyer-processors, social scientists, and fishery biologists. Short statements were made on the kinds of information each considered to be important for their specific decision-making, which were followed by comments and questions from the other participants. This produced a broader dialogue, emphasised some of the conflicts of interest characterising the different factions involved in fishery decision-making, and provided stimulus for many participants in choosing their own emphasis in the working groups for the following week.

A list of the documents submitted during the sessions of the first week is given in Appendix 3. All papers are published in full and/or in summarised form in the Proceedings of the consultation. The regional reviews describing environmental and resource changes and related fishery responses are published in FAO Fisheries Report No. 291, Volume 2; while papers providing localised and comparative studies, papers on impacts on human communities, and papers on application of methods and theory are published in the FAO Fisheries Report No. 291, Volume 3. A short summary review of the first week's technical presentations and discussions is also given here to provide readers of this volume with some essence of the basis of the discussions during the first part of the consultation. A full account of the results of the working sessions during the second week is given in the reports of the four working groups, which are included in full as main chapters of this volume.

5. SUMMARY REVIEW OF TECHNICAL PRESENTATION

The Technical Secretaries of the Expert Consultation opened the presentations to the technical sessions by introducing general topics of environmentally-induced changes exhibited by living marine resources in neritic environments, and the fishery, science and management problems which present themselves as these resources respond in various ways to the continuous barrage of natural and man-induced environmental changes.

The term neritic refers to the portion of the sea lying above the continental shelf; therefore all fish populations which are found and can be exploited in the marine habitat shoreward of the 200 m isobath can be categorised as neritic fish resources. This encompasses most of the highly productive fisheries of the world, and allows the inclusion of species with riverine, estuarine, lagoon or even oceanic life history phases, but which are fished primarily in the shallow margins of the sea, around islands or large areas like the Seychelles-Mauritius plateau, and enclosed seas such as the North Sea-Baltic complex or the South China-Sulu-Banda-Arafura Sea region. The latter resembles more a large estuary in species composition than an ocean-adjacent sea, and in most fishery contents is quite unlike many of the other broad shelf areas.

Figure 1 gives an equal-area review of the global distribution of neritic habitats in relation to land masses and also gives forty important riverine inputs which provide nutrients and nursery or feeding habitats for a large proportion of neritic fishery resources.

There is obviously more to fisheries catch than just shelf area in each country, and the importance of cultures, environmental features and accessible markets which are too often neglected, were also pointed out as major determinants of fishery evolution and of limitation to development.

During the overall habitat description, reference was also made to the always important early life history processes which set the long and very short term opportunities and abundance potentials for each species and, subsequently, for their fisheries. The relative importance of climate-ocean properties to local and regional zoogeographic characteristics was also emphasised. Long-term climatic, larger-scale changes are reflected in general north-south movements of the boundaries between tropical, temperate and boreal habitats. The transition zones are quite important features, with strong annual and inter-annual variations which are reflected in changes in species' compositions on those time scales when measured from specific geographic contexts. Transition zone fisheries exhibit the widest variations.

Reference was made to changes presently occurring in fisheries science, and particularly to the extended recognition that fish stocks do not live in isolation but form part of a larger ecological system, which have motivated part of the fisheries science community to reassess their conventional approaches for the purpose of reclassifying fishery resources into categories that more appropriately describe their expected patterns of variation and responses to system perturbations, and in order to investigate alternative management, monitoring and assessment techniques. Some of these concepts were discussed and several examples were presented at the end of the introduction by the Technical Secretaries, and some questions were posed about the underlying premises of conventional fishery assessment methods; one of the most important being whether it was possible to manage a fishery on a sporadically-peaking resource in such a fashion as to increase the long-term catch and decrease the short-term losses (often due to over-capitalisation and optimistic decision-making based on other than fishery and biological concerns).

The contributions from Japan, California, Peru and other eastern boundary current systems, and from the North Sea and the north Atlantic fisheries were particularly important in addressing this question and in documenting relevant fishery related changes and responses.

An informative example of the complexities observed in neritic fish resources as composition of species changes was provided by Kawai and Isibasi. From Figure 7 of their paper it is interesting to note that in different fisheries around Japan, the relative oscillations of each species increased with increased fishery landings during the early 1950's. Kawasaki also showed (Figure 1 of his paper) the catch pattern of three Pacific sardine species for the period 1900 to present, which speaks clearly for an underlying natural cause of the blooms, peaking and general return to very low levels of these resources. It is unfortunate, but quite evident, that current assessment and management methods cannot explain the bloom phase or manage fishing in a way that would sustain the peak period. In fact it is less a fishery management problem than was previously assumed, and the specific states in such a cycle where management intervention might be appropriate are well described in the reports of the working groups included in this volume.

Specific examples of oceanographic and meteorological variations directly related to system productivity, fishery changes or early life history successes or failures were described in the majority of the presentations. The topics of some more specific papers ranged from fishery independent variations in abundance to seasonal dependence of monsoon-dominated fish spawning cycles. Documented changes in species' composition due to species' interactions, predation and competition in the man-induced perturbations of the Great Lakes' systems, along with the specifics of the relatively successful rehabilitation of these once-threatened environments and their present inhabitants, were also described. In addition, short and long-term climatic and meteorological changes inducing fishery related changes in resource populations were discussed, tracing their respective ocean-wide or local-scale effects on fisheries.

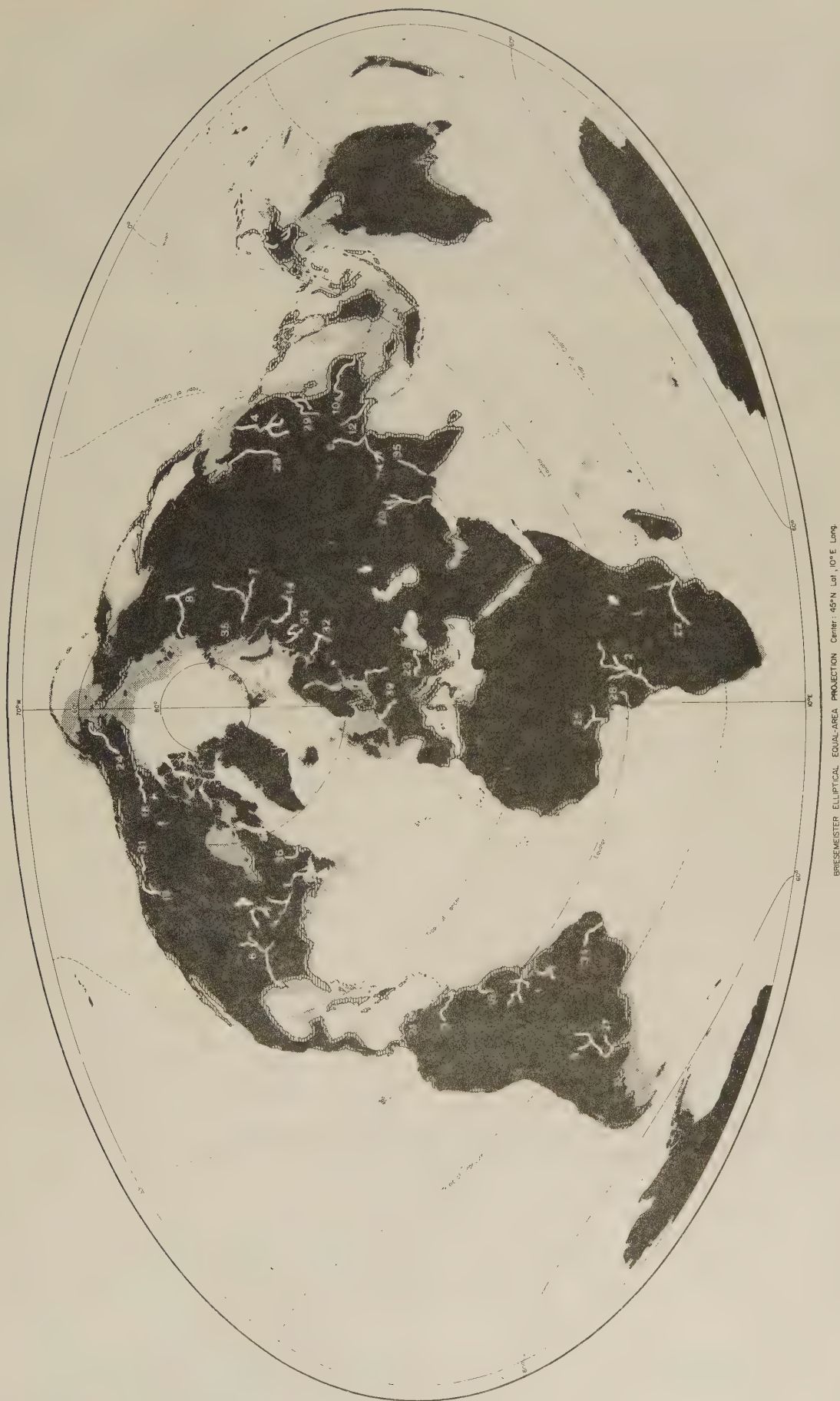


Fig. 1. Distribution of the world's neritic habitats in relation to the land masses and forty important river inputs

The consultation brought together the available expertise on eastern boundary current fisheries and oceanography, and their contributions alone form an invaluable collection of historical perspective, system description and comparisons of these, the world's most volatile and productive fishery systems. Several of the papers presented dealt with the eastern boundary current systems and their dominant anchovy, sardine, horse mackerel, hake, mackerel and bonito faunal complexes, thus extending the information available for an analogy of the type proposed by Bakun and Parrish (1980). Parrish, Bakun, Husby and Nelson reviewed and compared physical oceanography and fish reproduction of the four major eastern-boundary-current systems: California current, Peru current, Canary current and Benguela current. Their comparisons show that the four systems have superficial similarities related to seasonal latitudinal shifts of the atmospheric pressure systems of the sub-tropical transition zone and the relations between these and the continental topography.

There are also obvious system differences. For example, the minimum layer of oxygen off Peru is very shallow compared to that of the other three systems, and effectively excludes significant competition of mesopelagic species with those from above the thermocline-oxycline. In each system there are areas of intense wind-driven mixing which seem to be avoided by the pelagics, and the spawning grounds appear to be characterised by weak to moderate wind strengths, supporting Lasker's (1978) mechanism inducing survival (or de-stratification related mortality) of larval engraulids and other species. It was also pointed out that the spawning grounds of the major populations in these systems tend to be located downstream (equator-ward) of upwelling centres, and that smaller populations are supported pole-ward of the major upwelling centres, or in areas where upwelling is seasonal and spawning occurs when circumstances reduce the effects of offshore transport and mixing of the surface layers by the wind. In areas where other water-column-stabilising features are found, such as in the Columbia River plume area off the northwestern coast of the U.S.A., anchovy populations may take advantage of these and spawn out of phase with the other populations in the system. Larval fish transport processes are usually related to gyres in the systems but, as noted by Shelton and Hutchings (1982), off the southernmost tip of Africa, between Cape Agulhas and Cape Columbine, there is a coastal jet current which transports larvae from spawning areas to onshore nursery grounds.

Three types of fishery resources were identified in relation to the four major eastern boundary current upwelling areas:

- a) Stocks pole-ward of the local summer upwelling maxima (with total potential yields of 100 000 to 400 000 tons per year);
- b) stocks equator-ward of the summer upwelling maxima (with total potential yields of 800 000 to 2 000 000 tons per year); and
- c) stocks equator-ward of winter upwelling maxima (only in Peru, with total potential yield in excess of 10 000 000 tons per year).

One of the objectives of this consultation was to examine the effects of varying fishery resources on various sectors of society: fisherman, communities, investors, industry interests, governments, scientists, etc. A detailed description of specific, documented responses to the fishery collapses in eastern boundary current systems, with particular reference to the Peruvian fishery, was provided by Glantz. His review considered the individual's, the state's and international perspectives. Several fallacies or mythologies in applied fishery science were also addressed in this review.

The rehabilitation procedures of the Great Lakes were reviewed in an informal presentation by Magnuson, who introduced the concept of users and losers. The relative risks and socio-economic considerations relative to various characteristic fishery resource types were described by Beverton, who also discussed the role of scientists in international fishery management, and the general deterioration of related fora since their politicisation over the last decades.

The informal round-table on fisheries management and decision-making was held in the middle of the first week. It was initiated by a brief statement by the appointed chairman and by statements or comments from the other panel members, after which the floor was open to all participants for questions or comments. This gave rise to very interesting discussions which provided useful arguments for discussion during the working sessions of the following week.

The remaining sessions of the first week were devoted to specific research topics related to variations in parameters of interest to traditional conventional resource assessment, or to presently evolving multispecies and ecosystem approaches to resource monitoring and management. Evidence was presented for variations in growth rates; natural mortality or survival rates; distribution of eggs, larvae and adults on inter-annual and annual time-scales on distances as limited as a few hundred miles within a specific fishery population. The wisdom of employing constants in assessments in lieu of monitoring these variables was explored. Also certain indicators of stress were identified. For example, it was noted that anchovy populations from both the Peru and Benguela current systems somehow presaged environmental perturbations like the "El Niño". This has been shown by changes in fish reproductive behaviour and oil content, which are usually observed months or seasons prior to environmental phenomena being observed by man.

The problems of monitoring adequately such variations in complex fishery systems were discussed and the scales relevant to various important processes were defined. Finally, the first week's discussions were brought to a close with a summarisation of the various life history parameters, their variations and the relevance of certain procedures which have become rituals in stock assessment, in lieu of more informative and more empirical approaches to interpreting historical information. Considerable discussion was evoked and further development of ideas and queries about where specific approaches were appropriate, and where they were not, brought the consultation to a point where better understanding of the problems proposed in the introductory session was possible. Given a specific fishery, operating in a general system context: What were the major perturbing factors? What roles do man's activities play? and what specific measuring and monitoring methodologies would be necessary to adequately resolve the management alternatives available in order to sustain viable fishery resources and substantial, beneficial fisheries in the face of varying environmental conditions?

6. WORKING GROUP SESSIONS

Four major topics that reflected the available expertise at the consultation were chosen as a basis for setting up four working groups which met during the second week. These major topics were: resource studies and monitoring; environmental studies and monitoring; societal implications of varying fishery resources; and management implications and interactions.

A.D. MacCall was appointed chairman of the Working Group on resources study and monitoring (Working Group No. 1); A. Bakun was appointed chairman of the working group on environmental studies and monitoring (Working Group No. 3); M.H. Glantz was appointed as chairman of the working group on societal implications of varying fishery resources (Working Group No. 2); and J. Csirke was appointed chairman of the working group on fisheries management, implications and interactions (Working Group No. 4).

The chairmen of the four working groups were given the task of extracting relevant topical information from the presentations and discussions of the first week. They then opened the sessions of the second week with overview presentations of each of the above topics, followed by questions and discussions in plenary. The four working groups were then formed and scheduled in such a way as to allow a certain degree of interaction.

Each working group produced a draft report illustrating the results of its discussions, and conclusions and recommendations where applicable. These draft reports were presented and discussed in plenary at the end of the consultation, and are presented in final form here.

These four working group reports reflect the main results of this Expert Consultation. They address the problems associated with fish resource variability from different perspectives and contexts, and offer substantial directions and specific recommendations where appropriate. An important consideration while reading these reports is that they progress generally from consideration of single species fishery contexts in the biological section to wider context. The environment section necessarily incorporates physical, chemical and biological (predator and prey) considerations. The societal and, finally, the management implications sections address the more complex, but usually even less measured or monitored, human and political interactions.

In reading these reports, it is imperative to recognise that the sea, without man's influence, varies and that all resources in the sea are finite. Man is only one more very efficient predator, who at present is barely capable of effectively manipulating his own harvests.

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P A R T I I

REPORT OF THE WORKING GROUP ON RESOURCES STUDY AND MONITORING

by

A.D. MacCall (Chairman)*

ABSTRACT

This report sets up major guidelines for the study and monitoring of variable fishery resources and provides information which may be useful in evaluating needs and assist in selection of appropriate methods and studies. Major symptoms of adverse changes and potential collapse in fish resources are identified, and a variety of topics on monitoring of resource studies, fishery operations, and biological sampling are discussed.

1. INTRODUCTION

To be fully effective, biological monitoring and studies require consideration of fishery context and alternative methods. This report examines some of these considerations, and reviews some recent developments. This discussion is intended as a supplement to the many manuals presently circulating. Recommendations are difficult to make outside the environmental, biological, and socio-economic context of particular fisheries. In some cases, general needs are clear. For the remaining cases, this document provides information which may be useful in evaluating needs and choosing between alternative methods and studies.

This document is the product of the Working Group on Resources Study and Monitoring which met during the Expert Consultation on Neritic Resources. The composition of the Working Group varied during the Consultation. In addition to their technical input, R. Jones and I. Tsukayama provided valuable service as rapporteurs. Many other people participated regularly in the Working Group and/or provided substantial sections of this document. These included J. Alheit, B. Brown, J. Carscadden, R. Crawford, P. Fréon, M.L. Garcia, J. Lleonart, J. Lopez, A. Menz, S. Saccardo, H. Santander, R. Serra, G.D. Sharp, P. Shelton, E. Ursin and many more.

1.1 Working criteria

Fishery science stems recently from the much older European tradition we call "science". This tradition focusses almost exclusively on the academic pursuit of knowledge and the establishment of truth. However, fishery science extends beyond that tradition in that it forms a working basis for altering our world; that is, it is an applied science. The consequences of this aspect are not commonly recognised in fishery work, and in many respects call for a different approach to that which is taught in the university.

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Table 1. Comparative time scales

SCALE	YEARS	PHYSICAL	BIOLOGICAL	HUMAN
Diel	10 ⁻³		Tidal cycle Diel cycle Digestion	Daily activity cycle
Weather	10 ⁻²		Upwelling pulses Storms, destratification Stratification Serial spawning cycle	Weekly activity cycle
Seasonal	10 ⁻¹	Lunar cycle Seasons Monsoon	"Match-mismatch" Transport, dispersion of larvae Seasonal productivity	
Annual	10 ⁰		Recruitment Migrations	Financing-acquisition Vessel construction
Decadal	10 ¹	Kuroshio meanders Sunspot cycle Sahel drought El Niño Maximum length of data	Recruitment strings Species replacement Variations in total biomass	Government cycles, Fishery regulations Economic cycles Financing-payback Wars Vessel longevity Career longevity
Centennial	10 ²	Little ice age, Viking warming Dendrochronology Paleosediments		Civilization outbursts Artisanal fisheries
Millennial	10 ³			
Evolutionary	10 ⁴	Ice ages, formation and destruction of neritic habitat Panamic barrier, Mediterranean sea cycles	Subspeciation	

In addition to the traditional scientific criterion of knowledge, there are other criteria which should guide our efforts. Because the results of our work may contribute to changes in society as well as ecosystems, fishery scientists bear a burden of responsibility which is generally lacking in normal academic science. An important aspect of this criterion is timeliness. Many fishery analyses and recommendations are specific to the current status of the fishery, and lose value if they are not communicated quickly. The next criterion is closely related, and will be called appropriateness. This criterion is particularly important to the task of this Consultation; recommendations must not only reflect existing knowledge and responsible interpretation/application, they must also be suited to the needs of the recipient.

Fishery science is the application of ecological principles (in the broadest sense) to particular fisheries. Thus fishery models specifically, and fishery science generally, must be viewed situationally like situational ethics in the philosophical sense; any technique or measurement should not be viewed in the abstract, but in relation to the particular fishery under consideration. Unfortunately, this document, being a general review, necessarily violates the last criterion.

1.2 A note on terminology

The use of broad terms like pelagic or demersal when referring to fish groups causes a dichotomy that does not exist in nature. For example, pelagics are said to be highly variable, but haddock on Georges Bank has been more variable than herring in the Gulf of Maine, and mackerel in the recruited ages has a lower natural mortality rate than cod. Therefore fishery scientists should be specific in discussing these groupings and use species group designations (i.e. sardine/anchovy) rather than terms like pelagic. The characteristics upon which the groups are based should be explicitly stated.

2. A PERSPECTIVE OF VARIABILITY

Variability of fishery resources occurs on nearly all time scales. Moreover, biological variability is strongly influenced by physical or environmental variability on one side, and variability in the human sector on the other side (Table 1). Much of the dynamics of fisheries and the difficulties in their exploitation and management histories (e.g. booms and collapses) can be inferred from the interaction of forces acting on different time scales. As in the classical ecology of predator-prey cycles, delays in fishery exploitation response to resource abundance creates an inherently cyclic or unstable system. By recognising the nature of these interactions and designing appropriate and effective regulations, management can control and minimize these technological fishery cycles, within the bounds of natural environmental variability.

3. CAUSES OF CHANGES IN FISH ABUNDANCE

Fishery and resource monitoring often covers a wide selection of biological variables. This activity is done with the implicit assumption that changes in monitored variables provides information on the status of the resource, with emphasis on productivity and abundance. In order to evaluate the utility of fishery monitoring activities, it is useful to more explicitly examine the relationship between biological variables and causes of change in fish abundance.

Causes of change in fish abundance fall into five categories:

- Intraspecific dynamics, which includes compensatory mechanisms such as stock-recruitment relationships, density-dependent growth and cannibalism.
- Competition among species, which is of considerable interest but in practice is difficult to demonstrate conclusively.
- Predation, which is generally treated as natural mortality in fishery analyses.
- Fishing, or exploitation
- Environmental fluctuations, particularly abiotic factors and lower trophic level biological factors.

Table 2. Monitored biological variables that provide evidence for causes of variability in abundance of *Engraulis*. Symbols qualify the relationship (XX = strong evidence; X = evidence; i = indirect connection; ? suspected)

MONITORED VARIABLE	CAUSE OF VARIABILITY IN ABUNDANCE				
	INTRASPECIFIC	COMPETITION	PREDATION	FISHING	ENVIRONMENT
Population size	X	?	X	XX	i
Age structure of adults			?	XX	i
Fishing mortality rate				XX	i
Natural mortality rate			XX	i	X
Predator indices ^{1/}				X	X
Distribution (long term)		?		X	X
Distribution (short term)				X	XX
Recruitment strength	X	?	i?	i	XX
Condition factor/fat content	X	?		i	XX
Diet	X	?		i	X
Growth rate	X	?		X	X
Fecundity	XX	?		i	XX
Age/length at maturity	XX	?		i	XX
Egg/larval mortality rate	XX	?	XX		XX
Larval growth rate		?			X
Co-occurrence with other species ^{2/}	?	?	?	?	X
Sex ratio				?	
Seasonality of spawning				i	X

^{1/} Examples are guano production or seabird reproductive success

^{2/} This includes mixed schooling and geographic/temporal overlap

Biological variables, if properly monitored, can provide evidence of the causes of change listed above. Table 2 lists the most commonly monitored biological variables and the related causes of variability for the anchovy (*Engraulis*) fisheries. Nearly all variables are related to environmentally caused variation, and very many are related (at least indirectly) to fishing. Competition is a possibility in many cases, but no variable provides substantial evidence for competition. Intraspecific mechanisms are mostly evidenced by direct study of the fish, including its early life stages. Notably, the latter are some of the few variables not related to fishing. Some biological variables provide little useful evidence for causes of variability, for example, sex ratio is commonly monitored but is unlikely to provide useful evidence for causes of variability.

Table 2 would be different for other species of fish. Because *Engraulis* has been studied more than most species, the strength of evidence for other species will tend to be lower. In some cases additional biological variables would be appropriate. For example, northwest Atlantic herring have historically been impacted by disease, suggesting that monitoring for this factor would have some value.

4. SYMPTOMS OF ADVERSE CHANGES IN RESOURCE STATUS

Fishery stock assessment attempts to evaluate current stock productivity in relation to its potential productivity. This potential is estimated from historical resource monitoring, biological studies, and comparative information from similar species or fisheries. Experience has shown that fish stocks respond to exploitation in predictable ways, but environmental fluctuations often complicate the patterns. Because of this fundamental similarity among fishery responses, several models have been developed which concisely summarise the relationship between the fishery harvest and the resource. For example, as intensity of fishery removals increases, abundance decreases, mean age or size of fish decreases, and age at first maturity decreases. These changes in themselves simply reflect fishing pressure and compensatory responses. The level at which they reflect poor stock condition (i.e. performance falling below potential, due to excessive fishing) requires consideration of the context of historical levels and fluctuations as well as other features of the resource which may also have changed. For this reason, a generalised discussion of indicators of symptoms of adverse changes in stock condition is of very limited utility. However, for the purpose of discussion, Table 3 lists some common symptoms and indicators, their most likely interpretation, and some of the considerations that need to be taken into account.

Before concluding that a symptom signifies an adverse condition, the nature of the fishery and resource must be understood. Exploitation risk varies substantially with species and environmental characteristics, as shown in Table 4. With this background, the symptom in Table 3 must be examined for possible alternative causes such as environmental changes or changes in market demand. Once the symptom is accepted as a valid indicator of stock condition, the severity of the symptom must be judged on an objective basis. Usually this consists of using historical information in a fishery model which has well-established methods of interpretation. The model may also indicate the nature and extent of remedial action necessary to rehabilitate the stock.

The categories of diagnostic symptoms are few - relating to abundance, recruitment (incoming young fish), and relative intensity of harvesting. In addition, there are a variety of warning signs that are more difficult to interpret. Abundance is usually the most important indicator of stock condition, and for this reason a substantial portion of the research and monitoring effort should be devoted to this aspect. If a direct estimate of abundance is not available there may be other indicators such as the catch rate of the fishery, the geographic extent of the stock, or the status of more visible stock-dependent predators such as seabirds. Due to the relative imprecision of these auxiliary indicators, confirmation from more than one source is desirable. Analytical techniques such as production modelling may provide an estimate of "healthy" abundance levels (e.g. the level of abundance giving maximum productivity). Depending on the natural variability of the resource, a "warning" level of abundance might be half of the abundance giving maximum average productivity. A "danger" level could be similarly defined at a somewhat lower level.

Table 3. Most Common Signs of Deteriorating Resource Status and Potential Problems

SYMPTOMS AND INDICATORS	CONSIDERATIONS	INTERPRETATION
a) Abundance decrease Catch rate (CPUE) decrease Stock range decrease Change in species composition Change in predator indices	- Environmental influence - Changes in availability and vulnerability - History and definition of effort - Availability, vulnerability - Environmental influence - Environmental influence - Change in other species - Changes in market, regulations, fishing patterns - Environmental influence - Availability to predators	<u>Warning</u>, establish reference level <u>Warning</u>, <u>Danger</u> (CPUE often underestimates magnitude of actual decline), try production model <u>Warning</u> <u>Warning</u> <u>Warning</u>
b) Recruitment decrease Increase in mean age Anomalous fat cycle	- Environmental influence - Availability, vulnerability - Market, regulations, fishing patterns - Environmental influence - Normal patterns	<u>Warning</u>, establish reference level, try stock-recruit relationship, compare replacement level <u>Danger</u>, recruitment failure <u>Danger</u>
c) Fishing mortality approaches natural mortality Mean age/length approaches age/length at first maturity	- Environmental influence - Changes in availability, vulnerability - Environmental influence - Availability vulnerability - Changes in market, regulations, fishing patterns	<u>Danger</u>, try yield per recruit, production model <u>Danger</u>
d) Variable catch (after catch increase)	- Environmental influence - Market, regulations	<u>Warning</u>
e) Deviations from normal patterns Changes in spawning of recruitment pattern Changes in age/length at maturity Changes in fecundity Changes in size composition of catch	- Environmental influence - Availability - Environmental influence - Environmental influence - Environmental influence - Changes in availability, vulnerability - Changes in market, regulations, fishing patterns	<u>Warning</u> <u>Warning</u> <u>Warning</u> <u>Warning</u> <u>Warning</u>

Recruitment is the main source of fish biomass which replaces losses from the stock due to harvest and natural mortality. The higher the total death rate, the more sensitive is the resource to recruitment variability and/or failure. Recruitment fluctuations due to environmental variability are mostly unavoidable, although many resources show smaller relative recruitment fluctuations at higher parental stock sizes. When recruitment declines in parallel with decreasing parental stock abundance, there is a high potential for depletion ("recruitment overfishing"). When a history of recruitments is available, a plot of recruitment versus parental stock, with or without a fitted regression line, is useful to identify not only the average relationship, but often more importantly, to identify the existence of runs of above - or below - normal recruitment. Experience in Peru and Namibia have shown that anomalous fat or oil content patterns provide early warning of anomalous ocean conditions (e.g. El Niño) and related likelihood of future recruitment failure.

The activity of harvesting impacts a resource mainly due to the additional mortality (fishing mortality) imposed. There seems to be a consistent relationship between the magnitude of the natural mortality rate (M) and sustainable levels of fishing mortality rate (F). The relationship is the basis of the popular rule-of-thumb $F_{opt} \approx M$, but fishery experience has shown this often to be an overestimate of optimal F. Thus, a symptom of overfishing is a fishing mortality rate which approaches the natural mortality rate in magnitude. An alternative indicator is when mean age or length falls near the age or length at first spawning. Besides being evidence of relatively high fishing pressure, this condition indicates imminent recruitment decline due to lack of spawning potential.

Several other stock conditions can be taken as warning signs, but do not provide specific diagnoses. For example, increasing fluctuations in catch suggest a possible loss of compensatory capacity, as well as increased risk of collapse. Similarly, deviations from normal physiological or behavioural patterns may be due to environmental fluctuation or may be normal responses to fishing pressure, but should not be dismissed without consideration of possible deterioration of stock condition.

Importantly, Table 3 is not exhaustive. There are many more possible symptoms and indicators, some of which may have general utility, and many of which have specific utility in particular fisheries. Once again, it must be stressed that every fishery is in some respects unique, and the relevant symptoms and considerations vary accordingly.

5. FISHERY INFORMATION AND MONITORING

Relevant information for monitoring a fishery can be obtained directly from fishery related operations, by sampling, and/or through biological studies. There is extensive interaction among these categories of information as they are all related to fishery activities.

5.1 Operations

5.1.1 Historical documentation

There are direct effects on fishery operations due to sequential changes in either market conditions, processing capabilities, legislation or regulations, and environmentally mediated events or processes which need to be documented in order to provide information on shifts from one state of affairs to another. The necessary documentation is of low cost (i.e. a simple diary of crises or events) but is rarely done. Long-term fishery data series will often have associated sharp changes due to such problems about which information will need to be available to persons utilizing these data for analyses; otherwise mis-interpretation and bias may well result from such studies.

Records of the historical developmental stages of fisheries should include such information as: changes in fishing methods or gear, market developments (i.e. new products, new processing methods, etc.); market perturbations (i.e. labour or transport strikes, resource collapses, contaminant related legislation, flooding due to over-production, etc.); management and marketing regulations; and environmentally mediated perturbations such as El Niño events and longer term changes in species distributions, composition and abundances.

5.1.2 Catch

The basis of the fishery-marketing production is the species-product. Even within closely related species there are very distinctive differences between product acceptabilities and hence values in local and regional market places. Products vary in processing and distribution based on their market product characteristics. Even within species there are differential uses and values, e.g. herring and capelin roe, premium sashimi quality versus canning or reduction quality.

In the less complex fisheries where only one or a few fish are sought and landed, the species identification problem is minimal. Multispecies and high volume fisheries (i.e. for reduction) often do not offer opportunities for species stratification in data collection. In other cases the catches of complex, multispecies catch are sorted at the market place. Interpretations of catch and landings data from complex fisheries is potentially important to the general topics of changes in species distribution, abundance and composition.

In most cases (some artisanal fisheries might be exceptions), catch is the most important fishery datum. While resource abundance may be estimated independently, the volume of catch is a direct measure of fishery impact on the resource, and little planning or assessment can be attempted without catch information.

5.1.3 Logbook systems

A well-designed and well-executed logbook system can provide valuable quantitative and qualitative data about the fishery. Information that can be derived from these surveys may include catch, landings, effort, location of catch, stock identification, distribution, co-occurrence of different species, and discards. Since the information is being collected by non-scientific individuals on a cooperative basis, there is danger that the information may be poorly collected and of no use, or worse, misleading.

Besides providing quantitative and qualitative information about the fishery, logbook surveys have the advantage of being relatively inexpensive in terms of equipment, and of providing long-term indices of abundance. However, logbook surveys depend on cooperation of non-technical personnel and this cooperation may change depending on perceived influence of logbook information on fishing regulations (e.g. quotas). They are also relatively labour intensive and difficult to validate.

Due to the well-documented unreliability of catch-per-unit-effort (CPUE) indices of abundance, it is recommended that logbook systems be supplemented by independent sources of abundance estimates.

The design of the logbook will probably vary from fishery to fishery depending on such factors as fishermen's activities, the literacy of the fishermen themselves and the desired amount of data. However, the key to a good logbook is simplicity while still providing adequate information. The design of the logbook will undoubtedly undergo an evolutionary process as the scientist learns what the fishermen can or will do and the value of the information derived. Multiple logbooks (e.g. by species or requesting institution) should be avoided; such logbooks can be combined to minimise confusion. The information collected will vary according to the fishery and content. The logbook designer should consult the literature on logbook design, effort determination (also see the following section), and is advised to contact fishery scientists who have had experience in similar systems.

There are a number of factors involved in proper execution of a good logbook system. It is imperative that the scientist have close contact with the fishermen, preferably involving personal visits when the logbooks can be collected and discussed. Confidentiality of the information should be assured. Since the scientist is relying on the cooperation of non-technical people (i.e. fishermen) to collect the data, some method of verifying the information is necessary. There is probably no perfectly adequate way to validate all information, but the problem is of primary importance and should be addressed. It may be necessary to use a variety of validation techniques. Once the data are analyzed the fishermen should be provided with the results of the year's work written in non-technical terms.

5.1.4 Determination of fishing effort

The literature on effort determination is extensive, but severe problems remain. One problem is simply the terminology. Beverton and Holt used the word "effort" to mean an index of the instantaneous fishing mortality rate (proportionality was assumed). Gulland and others later used "effort" to mean a measure of nominal fishing activity. This evolution has been unfortunate, as it first begged the question, and then generalised the usage. The term "effort" probably should be discarded, but its usage is now firmly entrenched. The next best solution is to reserve the word "effort" for nominal fishing activity (so as not to beg the question), and to refer to the fishing mortality rate as exactly that.

Catch-per-unit-effort (CPUE) indices are compiling a growing record of biased and misleading performance. One of the major reasons is the information content implied by the nominal unit of fishing activity. In terms of information theory, fishermen search the grounds so as to reduce their uncertainty of making a catch. If the gain in information is closely related to the time or distance of search, this may be a useful nominal unit of effort measurement. However, modern technology supplies the fisherman with substantial and often overwhelming additional information by means of radio communication and aerial reconnaissance, and usually this information is not incorporated in the nominal unit of effort. The result is a tendency for the CPUE index to be insensitive to changes in fish abundance. Three recommendations are relevant here: 1) it may be best to define nominal effort in terms of the least information content, e.g. trips occurring on Monday or following new moons, when the fishermen know the least about the location of the fish; and 2) whenever possible go directly to the source of the information, e.g. use aerial scouting logbooks, recording the flight path and estimated quantities of fish observed; 3) it may be more useful to define a precise measure of CPUE with known bias rather than an imprecise CPUE which may be less biased (more nearly proportional to abundance). If the bias is known, it can be taken into explicit account.

Two complementary studies of effort are recommended. The first study is an analysis of the biological and human behavioural components of the fishing operation. In some cases a simulation model can be constructed, and the performance of various CPUE indices can be evaluated. This was first done by Paloheimo and Dickie (1964), and has been attempted for various fisheries since then (e.g. the Inter-American Tropical Tuna Commission recently developed such a model for the eastern tropical Pacific tuna fisheries). The utility of such models has varied, and the exercise is not necessarily productive.

The second study would be a world-wide comparison of CPUE indices where reliable independent estimates of abundance are known. For each fishery a variety of CPUE indices could be derived and their performance evaluated. Patterns of similarity could be established among similar measures of nominal fishing activity and among resources with similar biology and/or fishing operations. Such a study would be useful not only to aid choices of nominal effort definitions, but would also help document the general reliability and performance of CPUE measures.

5.1.5 Selectivity

The problem of selectivity is well-known for demersal species and appropriate solutions have already been proposed. In pelagic fisheries, especially when purse seines are used, a common assumption is that there is no selectivity. In fact there may be three types of selectivity on length. First, there is indirect mesh size selectivity, which is rarely observed because mesh size is adapted to the target fish length, and gilled fish in the seine are highly undesirable for the fishermen. Secondly, the fishermen are often able to estimate fish length before setting the net. They release the fish when they realize that the length is too small for commercial purposes. So selectivity is not done by the gear but by the fisherman in this case. This form of selectivity tends to vary with stock abundance and economic conditions, complicating CPUE indices. Thirdly, the most important effect of selectivity is due to the fish behaviour. Fish school according to size, and the school concentrations tend to contain schools with similar mean length of individuals. Therefore, it is recommended to try to stratify the sampling as much as possible in order to take into account the whole population structure. In some cases, a selectivity in sex ratio has been observed in pelagic species, for example some schools have a significant predominance of males or females showing different vulnerability to the gear particularly during the spawning cycle.

5.2 Sampling

5.2.1 Species and stocks, multispecies considerations

The available monitoring and sampling schemes for most fisheries give reasonably useful information by species or generic category; however, in many situations, due to either the integrative nature of some fisheries or the overlap between closely related species, proper data have not been obtained which would make it possible to stratify the catch by species or, even more difficult, to subspecific or "stock" levels, which need consideration in resource modelling and monitoring.

In most cases proper categories can be established by visual identification, perhaps aided by information on location of capture. However, there are also cases where stock identification is exceedingly difficult, e.g. anadromous fishes such as salmon, and local spawners such as herring. Some methods of distinguishing among stocks are given in Section 5.3.3.

Fishery sampling to monitor the catches of important species should be designed in a multispecies context. Often only the dominant species has been sampled. Subsequently, as the fishery changes and other species become more abundant in the catch, the early information on those species which dominate later catch are not available. Therefore the species structure of the entire catch should be determined. Then for each species the age and size structure should be determined. Finally, the biological characteristics of selected species should be measured - length, weight, maturity etc.

The sampling scheme should be representative both in a biological and a statistical sense. Sampling should be consistent so that comparisons can be made among years or sites. Statistical consideration should be used to design the sampling and determine sample sizes, but the designs and sample sizes should not be changed from year to year. When sampling methods are changed, details of the changes must be recorded so that the data can be properly interpreted in the future.

5.2.2 Sampling at sea

For reasons of costs, it is usually suitable to obtain all the parameters from landings (market sampling). When not possible, because fish are processed at sea, sampling at sea may be done by on-board biological technicians. If it is not possible to monitor fishing boats at sea, a research boat must be used. Two approaches are then possible. It may be effective to determine correction factors between market information and at-sea information (i.e. transformation factors, commercial categories, mean length, etc.). As a last resort, all estimations may be done with research vessels. In any case, control of market data validity is recommended through work at sea.

5.2.3 Industry production

It is often of benefit to monitor the processed output of fisheries' landings. Examples include the production of fish meal, fish oil, fish fillets or canned products. This information is usually accurate and should be readily available from fishing concerns and processing plants. An historical time series provides resource managers with an immediate perspective of trends in the quality and value of fish offloaded. For example, in the southern African purse-seine fisheries, large depletions in pilchard (*Sardinops ocellata*), horse mackerel *Trachurus trachurus* and chub mackerel *Scomber japonicus* resources have resulted in a considerable reduction in the quantity of canned fish being produced, in spite of combined-species landings remaining relatively constant.

Fat content of fishes often reflects their physiological and spawning condition, and may be a useful indicator of spawning difficulties. Fat content of fish can sometimes be easily and inexpensively monitored from information concerning processed products. This approach becomes of less value if the fishery operates on more than one species, as differences in fat content may exist. In such cases, fat content for individual species is best monitored by sampling at the offloading points.

5.2.4 Age and length

Once established, ageing methods (particularly age-length keys) tend to become set into the monitoring system. This can be very misleading (Kimura, 1977) and should be avoided by building into the monitoring system periodic re-evaluation of methods and interpretation. As international and regional comparisons of fisheries are being used more often, and as many resources extend across political boundaries, standardization of methods for ageing and measuring the length of fish is highly desirable. When a resource is being monitored by two or more countries, it is essential that agreement be reached on measuring techniques (e.g. size groupings and nominal birthday).

Finally, the recent development of attractive methods based only on length composition for the analysis of fish stocks should not prevent a serious attempt being made to use more traditional methods to assign absolute ages to individual fish. Also, length frequency methods need close examination for their properties of bias and precision.

5.2.5 Fecundity

The determination of batch fecundity used to be problematic for multiple spawning fish. Commonly, size-frequency diagrams of oocytes were established and the most advanced mode was assumed to represent the next batch to be spawned. This method lacks precision and is extremely time-consuming. Recently, a new method has been developed (Alheit *et al.*, 1983) wherein only hydrated oocytes are counted because they represent exactly the next batch to be spawned. This method requires that the females be collected at the right time of day, a few hours before they spawn.

5.2.6 Maturity

Maturity is commonly determined by means of macroscopic criteria. The disadvantage of this method is its subjectivity and lack of precision. Furthermore, its utility is doubtful because it was recently discovered that multiple spawning fish (e.g. anchovies) can spawn a new batch of eggs every 6 to 8 days at peak spawning time. This means they pass through 3 to 5 maturity stages - depending on the macroscopic criteria used - within a single week. Some stages are probably passed through within a few hours. The macroscopic criteria for maturity determinations are therefore of limited use for fish species with such a rapid oocyte development.

5.2.7 Sex ratio

Recently, some problems have been discovered in the determination of sex ratio of anchovies (*Engraulis*). Spawning behaviour includes segregation of males and females, which are ready to spawn, from the schools. These "spawning schools" have high vulnerability to capture, and usually have a preponderance of males. Also females have a higher vulnerability near spawning time than at other times during the oocyte development cycle.

5.2.8 Condition factor

Recent investigations have shown that gonadal hydration in anchovies can increase the female weight up to 30% within a few hours. Furthermore, schools which have hydrated females usually have a very high percentage of them. Care must be taken to modify the sampling appropriately and/or to develop conversion methods for such cases.

5.3 Biological studies

5.3.1 Growth

Two areas in which studies of growth (excluding physiological work) have provided useful information are tagging and examination of daily growth rings. Tagging may provide information on growth in the absence of other sources such as annual growth markers, and is also useful in verifying other methods of age and growth estimation such as modal analysis of length frequencies. Examination of daily growth rings is potentially very useful, but not yet resolved. Some recent work suggests that the frequency of growth ring information may be correlated with growth rate, and other studies have shown incidence of discontinuities.

5.3.2 Stomach contents

Interpretation of stomach contents is notoriously difficult for two reasons. First, very often it is not possible, because of lack of time or sufficient expertise, to determine the food items down to the species level. However, most ecological similarity indices used for comparing food spectra of different fish species are meaningful only if they are applied on the prey species level. The second problem is that digestion rates are extremely hard to determine. However, quantification of food consumption is totally dependent on a reasonable estimate of digestion rates, which probably even vary for different types of prey.

5.3.3 Stock identification

In ultimate usage, a "stock" is simply the segment of the population that is the basis of analysis and management. Thus, stocks may be defined in many ways, and some ways are more useful than others. There are a variety of issues to be considered, not all of which may have a biological basis.

Recently Booke (1981) defined the word stock for the Stock Concept International Symposium for application in fishery science. The general definition (i.e. vague) he gave was that "a stock is a species group, or population of fish that maintains and sustains itself over time in a definable area. In a more precise manner, stock can be ideally defined, where genotype is known, as a population of fish maintaining and sustaining Castle-Hardy Weinberg equilibrium. Where no genetic basis is available for characterising a stock, then phenotypic definitions need to be recognised so that a population of fish would maintain these characteristics and therefore could be called a stock." The latter case is the one generally applied today. Booke also emphasises the need to recognise stock genetic variability in management, given the guardianship implication of fishery management.

Probably more familiar to the usual stock assessment community is the assignment of stock labels by convention, based on fishing gear, geography, i.e. ocean hemisphere, or simple species designations, i.e. South Atlantic albacore, Baltic herring, etc. The numerous very tenuous stock structure hypotheses for most fish species have tended toward hemispheric or large regional approach to stock definition.

As a starting point in delineating "stocks" it should be obvious that the geographic location of reproduction is an important criterion, but that species may have variable geographic and temporally stratified reproduction, sustaining more complex rather than simple panmictic populations within any geographic context. These complex age-structures imply complex temporal and spatial patterns of reproduction.

The recent advances in thinking regarding marine teleost larval fish requirements have provided considerable basis for changing the usual premises applied to fish reproductive success. The concept of a "survival window" in time and space, arising from studies of the critical energetic requirements of larval fishes and the processes which promote them, is a key to better understanding the multiple cohorts of recruits entering most fisheries. This suggests that complex genetic composition might be a confounding issue, and that more definitive studies are needed.

Table 5 gives a synopsis of methods and data useful for population discrimination.

Methods based on characteristics of populations which are considered to be relatively sensitive, hence definitive, but which are quite discrete and can be categorised as being useful for both differentiation and consolidation of identities are: protein or enzyme characteristics, mitochondrial DNA comparisons, and immunological reactions. Methods based on chromosomal comparisons, colour patterns, and numerical or metrification studies are fraught with subjectivity and are integrative, hence less definitive, except for differentiation, where they are adequate inferential tools.

Table 5. Methods, Utility and Data Sampling Characteristics for Population Discrimination (from Sharp, 1983)

TECHNIQUE	METHOD	RELATIVE UNIT COST	DATA TYPE	DETERMINATION OF POPULATION CHARACTERISTICS	DEFINITIVE OR NOT IN DISCRIMINATION	1. WEAKNESSES & 2. STRENGTHS
A1 Protein characterisation	a. electrophoresis	low	non-parametric	sample size dependent	yes	1. sampling difficult 2. genetic basis
	b. electrofocusing	high	non-parametric	sample size dependent	yes	1. procedure slow 2. highest resolution
	c. purification and functional	very high	parametric	sample size dependent	can be	1. technique difficult 2. great sensitivity
A2 Chromosomal comparisons	a. karyotyping	low	subjective	can be useful	can be	1. requires big differences 2. genetic basis
	b. banding studies	moderate	subjective	can be useful	yes	1. requires large chromosomes 2. genetic basis
A3 Mitochondrial DNA	a. isolation and fractionation	moderate	non-parametric	sample size dependent	can be for familial studies or differentiation by area	1. tedious procedures 2. maternally inherited
A4 Colour patterns	a. pigmentation patterns	low	non-parametric	can be useful	can be	1. basis needs determining i.e. ontogenetic or hereditary 2. usually genetic basis

Table 5. Continued

TECHNIQUE	METHOD	RELATIVE UNIT COST	DATA TYPE	DETERMINATION OF POPULATION CHARACTERISTICS	DEFINITIVE OR NOT IN DISCRIMINATION	1. WEAKNESSES & 2. STRENGTHS
A5 Immunology	a. tissue typing, i.e. blood	low	non-parametric	sample size dependent	yes	1. sensitive to ambient 2. genetic basis
	b. microcomplement fixation	moderate	non-parametric	too sensitive	yes	1. very sensitive 2. species level tool
	a. hard part dimensions	low	parametric	can be useful	yes	1. basis needs determining samples must have common expectation 2. usually regionally specific, often genetic basis
B1 Growth and life history parameters	b. morphometrics of body dimensions	low	parametric	can be useful	can be	1. basis needs determining samples must have common expectation 2. usually regionally specific, often genetic basis
	a. age-growth by 1. annual ring on hard parts	can be high	parametric	often useful	corroborative	1. subjective 2. ease of collection
	2. daily growth rate	high	parametric	definitive	can be useful	1. needs calibration 2. gives rates on short-term basis

Table 5. Continued

TECHNIQUE	METHOD	RELATIVE UNIT COST	DATA TYPE	DETERMINATION OF POPULATION CHARACTERISTICS	DEFINITIVE OR NOT IN DISCRIMINATION	1. WEAKNESSES & 2. STRENGTHS
B1 Growth and life history parameters	a. age-growth by 3. tagging- recovery	high	estimation	not usually	corroborative	1. usually biases in release and capture 2. tagging changes natural patterns on short-term
	b. onset of maturity	low	parametric	useful	corroborative	1. differences can be induced by environ- mental changes 2. helpful in assessing changes
	c. fecundity	moderate	parametric	useful	corroborative	1. difficult to evaluate true number of eggs produced or hatched 2. often less important than the knowledge of where eggs are successful
B2 Distribution studies	a. mark and recapture	high	point A to B	can be useful	corroborative	1. needs substantive support data of A type
	1. tags and markers 2. hooks	low	point A to B	can be useful	corroborative	2. fraught with estim. errors but useful for assessing movements

Table 5. Continued

TECHNIQUE	METHOD	RELATIVE UNIT COST	DATA TYPE	DETERMINATION OF POPULATION CHARACTERISTICS	DEFINITIVE OR NOT IN DISCRIMINATION	1. WEAKNESSES & 2. STRENGTHS
B3 Natural tags	a. parasites	moderate	non-parametric	can be useful	corroborative	1. can be lost or transferred 2. area/host specific
	b. chemical/hard parts	high	parametric	can be useful	corroborative	1. can be transferred or source can be spuriously distributed i.e. currents 2. high information if source specifically located
B4 Meristic counts	a. gillrakers or vertebrae	moderate	parametric	not useful in tunas	no	1. highly variable in some species due to ambient 2. can indicate some species' differences

Table 6. Comparison and Evaluation of Methods for Monitoring Abundance

METHOD	BIOLOGICAL CONSIDERATIONS	ENVIRONMENTAL CONSIDERATIONS	SPECIES SPECIFICITY
Catch-per-unit effort (CPUE)	Sensitive to behaviour: school size, distribution, availability, mixed species. Difficult to define "effort"	Sensitive to physical influences on distribution and availability	Fair to Good
Cohort analysis (VPA)	Needs accurate ages, estimate of natural mortality. May be sensitive to population structure, mixing, non-constant natural mortality	Changes in natural mortality rate	Good
Cooperative "Eureka" fishing vessel surveys	Depends on survey method	Depends on survey method	Depends on survey method
Acoustic surveys	Sensitive to behaviour: depth, diurnal movement, mixed species, schooling density, evasion	May be sensitive to thermal structure of water column, sea state	Poor to good (unresolved)
Aerial surveys (or logbooks)	Sensitive to behaviour fraction of population visible at surface, diurnal migration, mixed species	Sensitive to thermal structure, bioluminescence, atmospheric and aquatic visibility, sea state, moon phase	Poor to good
Experimental Fishing	Gear avoidance, selectivity	Thermal structure, sea state, bioluminescence, moon phase	Good
Egg/larva Census	Diurnal distribution and evasion, patchiness, compensatory changes in vital processes, patchiness	Temperature, light, sea state	Good
Egg production method	Seasonality, patchiness reproductive behaviour and segregation of maturity stages	Temperature, sea state	Good, if eggs are identifiable
Tagging	Dispersion, tagging mortality, anomalous behaviour, recapture efficiency and intensity		Good
Predator indices	Sensitive to behaviour mixed prey species diet specificity and switching	Environmental influences on predators, rainfall on guano	Poor to good

APPROPRIATE USE	COST CAPITAL/HUMAN (Equipment)	TIMELINESS	IMPROVEMENTS NEEDED
Exploited segment, economics; bad for schooling, easily detected species, better for some demersals	Low/low to medium	One fishing season	Understand biases, definition of nominal efforts
Historical analysis - not current. Good for calibrating other indices	(Cost of data)/low	Several years late	Input (assumed) parameters, robustness needs examination
Regularly scheduled surveys, fishermen participate constructively	Low/low to medium		Calibration, coordination, navigation
Long time series best single fish and mid-water species. Unproven utility, especially in short-term surveys	High/medium	Synoptic	Calibration, species identification, avoidance
Rapid assessment of surface fishes	Low to medium/low	Synoptic to one fishing season (logbooks)	Fraction visible, calibration, species identification
Often use together with other methods, provides age structures, etc. unexploited resources	High/medium	Synoptic	Sampling design, avoidance, selectivity
Index of spawning biomass	High/high	6 or more months	Calibration, automation, understand biases
Estimate of spawning or total biomass, easily sampled and abundant Ichthyoplankton, also good for localized spawning areas	High/high	4 or more months	Knowledge of spawning behaviour, dispersal and predation
Not recommended for estimation of abundance	Low to medium/high	One fishing season to lifespan of fish	Reduce and estimate tagging mortality, understand behaviour
Supplementary and pre-fishery index of abundance	Low/low	Variable	Understand behaviour, needs more examples

Other useful methods for population discrimination are: growth and life history parameters, distribution studies through mark and recapture, natural tags, and meristic counts. These methods permit various levels of inference to be made but alone cannot be considered definitive. Unless far more data are collected or spawning populations and/or heritability are known and studied extensively, their uses are primarily for estimation. All population structure conclusions based only on these data are tenuous.

6. ABUNDANCE ESTIMATION

Fishery analysis and management usually requires knowledge of the abundance of fish. Sustainable yields tend to be closely related to absolute abundance, and the impact of harvest is mostly clearly monitored by relative changes in abundance. In most cases, development, calibration and monitoring of an abundance index should be given high priority. Due to the uncertainties associated with all methods of abundance estimation, it is generally undesirable to rely on a single method. Comparison and evaluation of methods for monitoring abundance are given in Table 6.

Commonly a fishery will provide information useful for calculation of CPUE indices and/or virtual population analysis (VPA) estimates. The former requires monitoring of nominal fishing effort and respective catches by a representative segment of the fishery, whereas the latter requires estimates of catches by age of fish for all segments of the fishery. In some cases fishery operations may also provide an index of abundance based on aerial scouting to locate fish. Due to the nature of fish behaviour and fishery operations, CPUE indices tend to underestimate changes in abundance, and therefore entail some risk in underestimating the magnitude of declines. VPA cannot provide reliable current estimates of abundance, since population estimates are reconstructed from subsequent catches. VPA estimates are typically about 3 years out of date.

Due to the shortcomings of these fishery-based abundance indices, fishery-independent estimates are desirable. Unfortunately, they also tend to be expensive. One method of reducing cost is cooperative synoptic surveys using vessels from the fishing fleet. This method has been used for 20 years in Peru, where it is called a "Eureka" survey. The utility and reliability of such a survey depends on coordination, navigation and calibration. The information obtained from calibration may also be useful in documenting changes in fishing power or catchability coefficient due to gear change and improvement, and may be a useful adjunct to normal CPUE monitoring. Frequently a cooperative "Eureka" survey will use the vessels' acoustic equipment. Since a large number of vessels can be mobilised, such a survey can cover the entire range of the stock. Also, the method can give the fishermen a sense of participation in management, and may help to reduce the alienation commonly existing between fishermen and managers.

Acoustic methods are still in a process of development, and have not achieved the promise envisioned over the last decade. The relation between biomass and acoustic properties is still uncertain in many cases, and species identification generally requires direct biological sampling, usually with nets. Acoustic surveys are useful when used in a long-term monitoring programme, but may be misleading when employed as a one-time estimate of absolute biomass. Different vessels and equipment can give different acoustic measurements, and cross-calibration is necessary for comparing survey results.

Systematic aerial surveys have been used for some surface-schooling pelagic species. Species composition and estimation of the visible fraction of the stock are problems that usually are solved by coordinating the survey with a research vessel. Generally, the research vessel is able to provide biological samples for age composition, stock identification, etc. in addition to its contribution to the abundance estimate. For some species, experimental fishing is a useful method in its own right.

Egg and larva surveys have been used widely, and are generally very species-specific. Major problems with larva census (standing crop) estimates are: 1) calibration difficulty, 2) variable fecundity and age of maturity, and 3) variable larva mortality rate. The last two problems act in a compensatory way, and will cause larva census estimate to be insensitive to changes in stock abundance. Thus results from larva census may be similar to CPUE, although for different reasons. A recently developed method called the "egg production method" (Parker, 1980; Alheit *et al.*, 1983) solves most of the problems with the

larva census. The method is based on estimated daily production of eggs (avoiding the standing stock problem), and uses histological examination of adult gonads to determine spawning rate and fecundity per unit biomass. The two sources of information are combined to give a direct estimate of spawning biomass, with statistical confidence limits. The egg production method is especially suited to multiple, serial spawners with easily sampled eggs or larvae and spawning adults. A variant of this method has been used to estimate size of local stocks of herring in the North Sea. In this case, herring are single-batch spawners, and fecundity is determined directly.

Tagging or mark-recapture methods have been attempted for neritic fishes, but tend to be unsuccessful as estimates of abundance. There are many unsolved problems with tag-related mortality, non-random behaviour, and the volume of marked fish necessary to achieve a useful marked-to-unmarked ratio. Tagging seems to have more useful application in studies of growth and/or migration.

In some areas it may be possible to develop "predator indices" of prey abundance. For example, guano production by seabirds in South Africa seems to be related to the biomass of surface schooling pelagic fishes such as anchovy and sardine. There are presently no cases where predator indices are sufficiently precise for direct use in fishery management. However, they are inexpensive and can provide useful information on relative abundance, migration, and ecological relationships. Further study of the predator species is necessary to interpret the predator index, particularly with regard to behavioural and environmental sources of variability.

7. RECRUITMENT FORECASTS

Both the nature of recruitment forecasts and their usefulness depend on the management objectives of the fishery (i.e. the nature of optimality). The more clearly defined the objectives are, the better we can evaluate the utility of a recruitment forecast. The recruitment forecast can take several forms, each associated with costs and levels of precision. The best form and associated cost and precision will depend on the management objectives. Three useful forms are:

Continuous form. Here recruitment is estimated as a continuous variable, generally with statistical confidence limits. The estimate may be either an index (relative recruitment), or if the proportionality can be determined, it may be an estimate of absolute recruitment.

Discrete form. Recruitment may be forecast as falling into one of several categories. A relative estimate may be "above-, about-, or below-normal", and an absolute estimate may be "greater than R_2 , between R_1 and R_2 , and less than R_1 ". The probability of falling in the wrong category may be estimated, and will be high as we approach the divisions between categories. On the other hand, the sampling effort and associated cost may be much lower than for the continuous form of forecast.

Decision form. This is a variant of the discrete form and may be best suited for the objective of catastrophe prevention. Recruitment would be classified as above or below a critical value, and can be statistically treated by a hypothesis test. Without getting too deeply into statistical theory, it is important to discuss the types of errors that can occur. Consider the following possibilities

		Decision	
		R is below critical	R is safe
Actual condition	R is below critical	Correct	Wrong (Type I error)
	R is safe	Wrong (Type II error)	Correct

When we treat "R is below critical" as the null hypothesis, we can make two kinds of errors. In one case we may let the fishery continue without necessary preventative action (Type I error), and in the other case we may take preventative action when it actually is not necessary (Type II error). If we choose criteria making one type of error unlikely, we increase the probability of making the other type of error, given the same sampling intensity (i.e. precision). The manager must decide on the relative seriousness of the two types of errors; however, the objective of catastrophe prevention argues that the probability of making a Type I error is kept small.

While it is desirable to develop a recruitment forecast based only on causative or correlated environmental variables, few (if any) known empirical relationships are precise enough to use in this manner. Presently the best possibilities for a useful recruitment forecast are direct or indirect sampling of young fish (pre-recruits). Nets can be used, but young fish are highly evasive, and there is a need for improved sampling gear and techniques. Indirect sampling includes acoustic surveys which may use swim-bladder resonance to identify species and size. In some cases a pre-recruit survey could concentrate on indicator areas where these fish are known to concentrate.

In general, the younger the age at entry to the fishery, the more difficult it is to obtain a timely, useful, recruitment forecast. Ironically, it tends to be these short-lived, early recruiting species that are most in need of recruitment forecasts.

Early fishery indications of recruitment strength, such as catch rates of young-of-the-year, may be combined with the recruitment forecast to update the estimate. Here, increased precision is purchased by a delay in time; however, management may easily incorporate a two-step progressive response as the recruitment estimate gains precision.

Bayesian statistical methods may provide increased precision and reduced risk at little cost if a stock-recruitment relationship (including the extent of natural variability) has been developed for the resource. The stock-recruitment relationship provides an *a priori* probability distribution for recruitment, and the recruitment which has been forecast may be assumed to be a sample from this *a priori* distribution. Another attractive feature of this approach is that a risk function (defining the seriousness of various errors) may be introduced to the recruitment estimator, so that sensitivity to catastrophic recruitment failure (or other conditions) can be explicitly incorporated.

Recruitment strength is often positively serially correlated, that is successive recruitments tend to be somewhat similar. This is due to the stock-recruitment relationship (stock itself being serially correlated due to persistence of year-classes), and also to the tendency for environmental conditions to persist over more than one year. A high serial correlation argues that response to unusual recruitment strength should be somewhat disproportionate, because the next year is likely to produce similar conditions.

8. ECOSYSTEM CONSIDERATIONS

Recent years have seen many calls for "multispecies" and "ecosystem" approaches to fishery analysis and management. While the theoretical wisdom of such approaches is clear, our practical knowledge tends to fall far short of the level necessary for successful implementation. In fact, our knowledge of single-species dynamics is often only marginally sufficient for single-species fishery management, and is wholly inadequate as a foundation for multispecies models.

For example, small "forage" species such as anchovies contribute to the diets of larger fishes as well as seabirds and marine mammals. Multispecies management would require recognition of the trophic value of unharvested anchovies as well as the value of the harvested fish. However, being planktivores, the anchovy undoubtedly consumes eggs and larvae of larger predatory fishes, and may have a negative value in that respect. The balance between these aspects could be investigated by multispecies modelling, but the information required to implement such a model would require an expensive programme of fishery-independent investigation.

8.1 Habitats and fishery characteristics

There are a wide variety of neritic ecosystems. These vary with latitude as well as with habitat. Table 7 (a), (b) and (c) examines the relationships of neritic habitats to their fisheries in tropical, sub-tropical and temperate zones.

Table 7a. Habitats and Fishery Characteristics in Tropical Zone (Surface Temperature in the 23-29°C Range)

	ESTUARINE - DIVERSE	HARD BOTTOMS, REEFS	SOFT BOTTOMS, RIVER DELTAS	COASTAL UPWELLING PELAGIC	REEF OR ISLAND ASSOCIATED PREDATORS
Resource base	Shrimps, juvenile marine fishes, reproductive adults, freshwater spp. Panaeids, Mugilids, Perciformes, Selacians	Herbivorous and piscivorous spp.	Numerous species from all trophic levels	One to three main species and predators	Tuna, Billfishes, large Jacks
Main taxa exploited		Perciformes	Perciformes	Clupeoids, Scombrids, Carangids	Thunnus, Katsuwonus, Istiophoridae, Perciformes, Carangids, Serranids
Stock density at virgin state	Variable, medium, seasonal	High, apparently stable	Medium to high	Extra-variable low to high	Low to medium
Main gears employed	Seines and artisanal gear	Traps, hand lines, some destructive gears	Demersal trawl and artisanal	Seines	Trolling, pole and line, handlines and artisanal
Depth strata exploited	Top to bottom	To about 100 m	Top and bottom ≈100 m	Mixed layer	Top to bottom depending on species
Significant artisanal fisheries	Yes	Yes	Yes	Some	Yes
Catch used for	Food and export	Food, photos	Food and export	Food and reduction	Food and export
Quality and value of products/kg	Usually good medium	Usually very high	Varies with treatment	Usually poor low	High, but marketing problems
Year class patterns	Fairly stable	Possibly unstable at species level, stable at community level	Little information but appears to be variable on small scale	Unstable but can be high for a long period	Continuous recruit- ment, some seasonal availability
Knowledge of biology of resource	Good	Reef fishes not well known as resources	Poor	Good	Variable
Stocks exploited by	Local fishermen	Local fishermen, tourism	Local and some dis- tant water fleets	Local and often dis- tant water fleets	Mainly local fishermen
Major Perturbations	Man-made changes in environment as well as biological-ocean ones	Reef destructions some reef predators e.g. crown-of-thorns	Fishery induced and localised biology	Climatic trends, weather events	?
Scope of expansion	Little	Little	Usually not but some areas could have	Varies with resource flux	Not great
Seasonal limitations	Flooding	Little	Monsoon or tropical storms	High winds or tropical storms	Monsoon or tropical storms

Table 7b. Habitats and Fishery Characteristics in Sub-Tropical Transition Zone: Eastern Boundary Currents
(Surface Temperature in the 15-23°C Range)

	COASTAL/LAGOONS	SHELF-ISLAND AGGREGATIONS	PELAGICS	SUB-SURFACE LAYERS
Resource base	Small pelagics, small predators, young marine fishes	Jacks, Bonitos, Tunas, Squids, Spanish Mackerel	Anchovy, Sardines, Mackerels, Jack Mackerels, Bonito	Adult Jack Mackerels, Hake, Redfish, Bonitos
Main taxa exploited	<u>Engraulis</u> , <u>Opisthonema</u> , <u>Sphyraenidae</u> , <u>Caranx</u> , <u>Serranidae</u>	<u>Seriola</u> , <u>Sarda</u> , <u>Thunnus</u> , <u>Loligo</u> , <u>Scomberomorus</u> , <u>Acanthocybium</u>	<u>Engraulis</u> , <u>Sardinops</u> , <u>Scomber</u> , <u>Trachurus</u> , <u>Sarda</u> , <u>Sardina</u> , <u>Sardinella</u>	<u>Trachurus</u> , <u>Merluccius</u> , <u>Sebastes</u> , etc.
Stock density at virgin state	Variable to high	Seasonally high	Variable to high	High
Main gears employed	Seines, artisanal	Trolling, hand line, seining	Seines	Trawls
Depth strata exploited	Top to bottom	Surface and bottom	Surface	Mid to deep, i.e. 25-1000 m
Significant artisanal fisheries	Yes	Yes	Not usually	No
Catch used for	Food.	Food and export	Food, reduction, export	Export
Quality and value of products/kg	Mostly low	High	Mostly low to medium	Medium
Year class patterns	Highly variable	Variable	Eruptions and failures	Eruptions and failures
Knowledge of biology of resource	Poor	Poor to fair	Some very good	Fair
Stocks exploited by	Local fishermen	Local and foreign fishermen	Local and foreign fishermen in some areas'	Often foreign fishermen
Major perturbation	Cyclic or epochal shifts in ecosystem, i.e. birds and predators	Long-term population cycles due to climate-ocean events	Sporadic and epochal trends apparently change system, i.e. El Nino and Sahel cycles	Sporadic and epochal trends apparently change system, i.e. El Nino and Sahel cycles
Scope for expansion	Nil	In some areas, very high	Usually not	In some areas, very high
Seasonal limitations	Cyclic changes in tropical/temperate influences	Migration and distribution associated with changes in location of transition zone	Few	Few

Table 7c. Habitats and Fishery Characteristics in Temperate to Boreal Zones (Surface Temperature in the 4-15°C Range)

	PELAGIC	SUB-SURFACE LAYERS	ISLAND OR PLATEAU ASSOCIATED
Resource base	Capelin, Herrings, Sprats, Mackerels, Sardines, Osmerids	Pollock, Codlike fishes, Flatfishes, Hakes, Redfishes, large Jack Mackerel	Codfishes, Hakes, Herrings, Pollock, Flatfishes
Main taxa exploited	<u>Clupea</u> , <u>Sprattus</u> , <u>Scomber</u> , <u>Sardinops</u> , <u>Mallotus</u>	<u>Theragra</u> , <u>Gadoids</u> , <u>Merluccius</u> , <u>Sebastes</u> , <u>Trachurus</u> , <u>Pleuronectids</u>	<u>Gadoids</u> , <u>Merluccius</u> , <u>Clupea</u> , <u>Theragra</u> , <u>Pleuronectids</u>
Stock density at virgin state	Variable to high	Generally high	Variable to high
Main gears employed	Seines	Trawls, gillnets, setlines	Trawls, setlines, seines
Depth strata exploited	Mixed layer	Mid to deep	Top to bottom
Significant artisanal fisheries	No	No	No
Catch used for	Food and export	Food and export	Food and export
Quality and value of products/kg	Medium - high	Medium - high	Medium - high
Year class failures	Common	Occasional	Common
Knowledge of biology of resources	Good	Usually good	Usually good
Stock exploited by	Local and foreign fishermen	Local and foreign fishermen	Local and foreign fishermen
Major perturbations	Climatic shifts	Ice and climatic trends	Climatic trends
Scope for expansion	Varies with resource abundance	Not in northern hemisphere	Not usually
Seasonal limitations	Migratory and reproduction cycle	Migrations and storms	Migrations and storms

8.2 Interaction between pelagic planktivores and their physical environment

Dramatic changes in the physical environment and the abundance of neritic fishes provide a dynamic environment for major neritic fisheries. Understanding and predicting some of the fishes' responses to the physical changes, and the ecosystems' responses to the changes in abundance of the fishes, may assist in formulation of management recommendations.

First, the physical changes, such as El Niño, are characterised by major displacements of water masses. The boundaries between water masses change geographic position. Many of the neritic fishes, such as anchovies, sardines, mackerels, etc., are pelagic and are expected to respond as volitional nektonic organisms by redistributing geographically in respect to the temperature and other characteristics of the water. Fishes have well-defined preferences that direct these movements in oceanic gradients. Laboratory estimates of temperature and other preferences, along with synoptic information on physical oceanography, may help explain north-south displacements of warmer-or-cooler-living fishes, restrictions in the total area of preferred environments, and replacements in a single geographic location of one species by another. In addition fishes generally have the highest growth rates at the preferred temperature if food is abundant. If food is less abundant there is some evidence that they can and do maximise growth by moving to cooler temperatures. A hypothesis on how fishes distribute in an environment which is spatially heterogeneous in respect to food and temperature is developed in Crowder and Magnuson (1983).

Second, the large changes in abundance of certain neritic fishes such as anchovies and sardines cannot occur without these fishes having an influence on their ecosystem. The most direct way that consumers modify their environment, especially when at high densities is by the consumption of their prey organisms. Consumers can reduce the abundance of their prey, and if they tend to select larger zooplankton, for example, they can alter the size distribution of their prey. When the larger planktons become rare it has been observed that fishes grow rapidly to a given size and then have marked reductions in growth rate. They reach a plateau at this size because larger particles on which they can feed with lower energetic costs are no longer available. Thus the increased cost of preying on small organisms reduces their net energy intake and growth slows or stops. The changes induced in the plankton can alter the suitability of the prey size spectra for other zooplanktivores and can cause decreases in abundance of other species. When the dominant zooplanktivore decreases in abundance, these pressures are removed and other species may then do better. Egg predation may also be a more critical factor during periods of high fish abundance when zooplankton particle size distribution is modified.

Other changes induced by a consumer include altered consumption rates by their prey species on organisms further down the trophic structure, and altered patterns of remineralization of nutrients, i.e. nitrogenous compounds may be concentrated or retained in near-surface waters. Also, primary production can be altered by fish-induced concentrations in nitrogenous compounds and by altered biomass of the phytoplankton owing to consumption of phytoplankton by the fish or by the prey organisms of fish. These consumer effects have been observed and documented in pelagic ecosystems of lakes, and some have been observed in marine environments (Stroud and Clepper, 1979).

8.3 Diet overlap of anchovies and sardines

There has long been speculation about possible feeding competition between adult sardines and anchovies as an explanation for replacement within this species pair; however, no evidence has yet been presented which proves feeding competition between both species. One reason for this fundamental lack of knowledge is that it is notoriously difficult to quantify the food habits of many planktivorous fish species because of the high taxonomic diversity of their food items. Furthermore, both sardines and anchovies can change their feeding mode from filtering to biting, depending on prey size. Secondly, even if it were shown that the food spectra of both genera overlap to a high degree, it would not mean that they were competing for food. If the carrying capacity of the environment is high (in this case, if plankton is highly abundant), both species could occupy exactly the same feeding niche without competing at all. This would be "feeding co-existence" in the sense of Jones (1982). Nevertheless, although sound evidence on feeding competition between sardines and anchovies has never been presented, some scientists ignore the weakness of existing data and report feeding competition to be one mechanism to cause replacement within this species pair. A careful study of the habits of both species in the same environment

together with a parallel analysis of their food source and energetics is needed to clarify the relationship between these two fishes and to end the long record of speculation on this subject.

The same study could also examine the effects of predation and cannibalism on eggs and larvae. This phenomenon has already been documented (e.g. Santander *et al.*, 1983), and its influence on anchovy-sardine relationships is similar to that expected from competition, although the mechanism is rather different.

8.4 Species interaction modelling in fisheries

It should be borne in mind that a model is no more than a rational formulation of the modeller's ideas. The model when applied, shows whether available information is consistent with these ideas. When it is found to be, the output from the model often indicates what further information might put the ideas to another and more rigorous test.

Biological interaction models may be entirely empirical (e.g. based on polynomial expressions), or may be based on more familiar fishery models of the Schaefer production model (Lotka-Volterra) type, or the more detailed Beverton-Holt type. The latter category includes multispecies cohort analysis models being used to analyse mixed catches in the North Sea. The production model approach seems to disclose too little biological information, although some sound reasoning can be based on their concepts and assumptions.

Generally multispecies models tend to be either simple and unrealistic, or difficult to handle and definitely no tempting tool for beginners in the art of modelling. An interesting exception is perhaps the approach by Larkin and Gazey (1982) to modelling the development of the fisheries of the Gulf of Thailand by means of a simple biomass model. It can be handled by a small personal computer and requires relatively little programming expertise. It models a closed system, but should be easily adaptable to an open system like a zone of coastal upwelling by adding migration terms.

It might be an interesting exercise to formulate the Peruvian system as conceived by Walsh (1981) in terms of the Larkin and Gazey approach. Walsh adds to the common knowledge of Peruvian anchoveta history the observation that sedimentation of organic matter increased when the anchoveta stock collapsed. This may provide the necessary information for beginning to understand the interactions within this highly variable system.

A system such as that off Peru presents a challenge to the ecosystem modeller. The greater the perturbations to be described, the better the model must be. It is no problem to model a system in a steady state, but such a model is likely to prove unsatisfactory when a perturbation occurs, and it is unlikely to contain the necessary mechanisms to respond realistically to a perturbation not experienced before.

9. EQUIPMENT AND FACILITIES

9.1 Equipment

As in most other fields of natural science, fishery science is more limited by human creativity and resourcefulness than by the sophistication of its equipment. In most cases adequate fishery research requires only a few basic items of research equipment (although sophisticated equipment may be required for particular investigations). Computing facilities are quickly becoming essential to processing and analysis of large data collections and development of complicated models. However, a large computer is seldom necessary for this purpose; small and inexpensive desktop computers with appropriate data storage devices are often sufficient and do not require expensive maintenance.

9.2 Research vessels

It is often financially inadvisable to acquire a large research vessel. Sometimes large vessels are required due to long-range or heavy weather operations, but in other cases large vessels are thought to be associated with increased agency prestige. In either case, the reason for acquiring a large vessel (often at nominal cost) must be balanced against the real costs of operating the vessel. In most cases the operating cost is the decisive factor in the success of a seagoing research programme. Also, the

vessel should be designed to use equipment (engines, hydraulics, electronics, etc.) for which spare parts and service are readily available in the country of use (as opposed to the country of construction); otherwise, equipment repairs may be very expensive and take many months, with associated losses of programme funds and time.

9.3 Fishing gears

A great deal of money and effort is often wasted because inappropriate gear is purchased for a research vessel, particularly when this involves purse seines and trawls. Account should be taken of the type of fish and the quantity required as well as the capabilities of the vessel and its crew. If expert advice is not readily available, judicious recourse should be made to consultants.

10. BIAS IN FISHERY SCIENCE

Fishery scientists have a professional and ethical responsibility for acquiring, improving and evaluating their tools ("tools" include analytical techniques, models, unifying concepts, etc.). Of these three activities, evaluation is the most difficult and the most necessary. A brief review of assorted biases in fishery information and analysis suggests a very important and disturbing conclusion: the preponderance of errors in fishery science are conducive to overexploitation.

This bias does not seem to stem from the theoretical basis of fishery science. Rather, it is mainly associated with methods of application and measurement which are strongly influenced by circumstances. The following examples may help clarify the nature of the problem.

10.1 Estimated change in abundance

If the method of estimating abundance is insensitive to changes in true abundance, fishery analysis may underestimate the true degree of impact on a resource. The associated yield models will tend to overestimate optimal harvesting intensity.

Catch-per-unit-effort. This popular index is often insensitive to changes in true abundance, particularly in pelagic surface (e.g. clupeoid) fisheries. Both fishing and fish are distributed non-randomly. As the resource declines, school size may remain unchanged, and the range of the resource may contract while abundance at the center remains relatively constant. Fishermen respond to decrease in abundance by adaptive gear changes and attrition of less effective vessels, keeping catch per nominal unit of effort high. In multispecies fisheries nominal effort directed towards a given species is often defined as the effort which resulted in catching that species. This results in an insensitive CPUE.

Developing fisheries. A period of learning often occurs when a fishery is initiated. The early fishery working inefficiently on high abundance will later become an efficient fishery working on decreased abundance. During the transition catch per nominal effort will not decline, giving the appearance of a resilient resource. Also, as the geographic range of a developing fishery expands, the fishery may progressively exploit virgin segments of the stock for a prolonged period.

Ichthyoplankton surveys. Compensatory changes in fecundity, age of maturity and egg or larval mortality will cause these surveys to underestimate changes in stock abundance.

Acoustic surveys. At high densities fish in the center of schools may not be detected quantitatively, whereas at lower densities detection improves.

10.2 Fishery information

Catch. Non-reporting of catch can cause inadvertent overexploitation. Quotas enacted to protect the resource may result in increased non-reporting or misidentification of species.

Progressive improvement. Progressive improvement in monitoring may give a false impression of stability while catches are actually declining.

10.3 Models and statistical procedures

Functional regression. Use of the standard "Y on X" regression rather than a functional regression (recognising observation error in the independent variables) will underestimate the absolute value of the slope of the regression. In production models this often produces overestimates of MSY and optimal effort. In stock-recruitment relationships this produces an erroneous impression that recruitment is independent of stock size. Functional regressions have not yet been developed for non-linear application, so this bias is presently unavoidable in estimating non-linear regression models.

Random variability. Random variability and serial correlation of recruitment are factors which cause realisable yields to be less than deterministic maximum sustainable yield (MSY). Nonetheless, deterministic MSY is often used as the criterion of a fully developed fishery.

Potential yield. The popular Alverson-Pereyra-Gulland potential yield estimate ($Y = 0.5 MB_{\infty}$) tends to overestimate realisable sustainable yields. Fisheries are often initially developed on abnormally high-resource abundances, giving an overestimate of virgin abundance B_{∞} . The formula also implies that recruitment at MSY is equal to virgin recruitment, which is seldom the case. For highly fluctuating resources potential yield may not be appropriate to lower levels of abundance cycles. Unfortunately the potential yield estimate tends to be adhered to long after improved fishery information becomes available.

Model formulation. Most fishery models are formulated in deterministic equilibrium-oriented terms with smooth transitions among states. These models will overestimate resource stability if the true behaviour is sustained disequilibrium, with catastrophes or multiple stable states. It may be attractive to assume a constant multispecies productivity, but experience shows that total productivity may be low for several years during transitions (if this concept is valid at all).

10.4 Wishful thinking

Fishery scientists and managers, as well as fishermen, want to see a healthy, productive resource. There may be an unconscious tendency to overestimate productivity or abundance (this has been observed in other sciences, e.g. Gould, 1978). For example, a suspected bias toward overestimation of true abundance is generally tolerated whereas a suspected bias toward underestimation is viewed with more severe criticism.

10.5 A prescription

This dangerous and pervasive direction of bias can be avoided to a large extent, but the prescription is not easy:

- Scientists and managers must be aware of the tendency toward inadvertent overexploitation, and the various ways this can happen.
- Methods and analyses should be subject to periodic critical review to detect these kinds of errors.
- Appropriate methods are important. This often means a more lengthy and detailed analysis. Short-cut methods are often dangerous if treated as a final product.
- More robust methods and models need to be developed. Also, the inherent biases of existing methods need to be investigated and better understood.

11. SUMMARY

Fishery science requires working criteria of knowledge, responsibility, timeliness, appropriateness, and a situational viewpoint (consideration of context).

Variability of physical, biological and human subsystems of fisheries occurs at all time scales, and their interactions are important to management.

Changes in abundance may be due to intraspecific dynamics, competition, predation, fishing, or environmental causes. Variability in fishery and resource data elucidate these causes.

Various symptoms of adverse changes in resource status fall into three main categories: decreases in abundance or recruitment, and high relative fishing intensity. These symptoms must be considered in a fishery context, from which reference levels can be established.

A variety of topics on monitoring of fishery operations and biological sampling are discussed. A historical narrative or journal should be maintained in addition to such data as catch and effort. Sampling should recognise multispecies aspects of catches.

An extensive survey of comparative catch-per-unit-effort abundance indices would be useful in evaluating the performance of that index and in helping define best available measures of nominal fishing effort.

Many standard procedures (age-length keys, maturity criteria, fecundity determination) should be reviewed in light of recent developments in technology and advances in understanding.

Stock identification continues to be an important but difficult task. Methods continue to be developed, but many require sophisticated technology.

Various methods of abundance estimation are compared, with no single method showing superiority. It is advisable to monitor abundance by more than one method.

Recruitment forecasting is still at a primitive stage of development. The nature of the forecast depends on the way it is used in fishery management; for most purposes, a qualitative "above-, about-, or below-normal" may suffice.

Recent calls for multispecies and/or ecosystem management are unsupported by current knowledge. This area provides the greatest challenge for research and modelling.

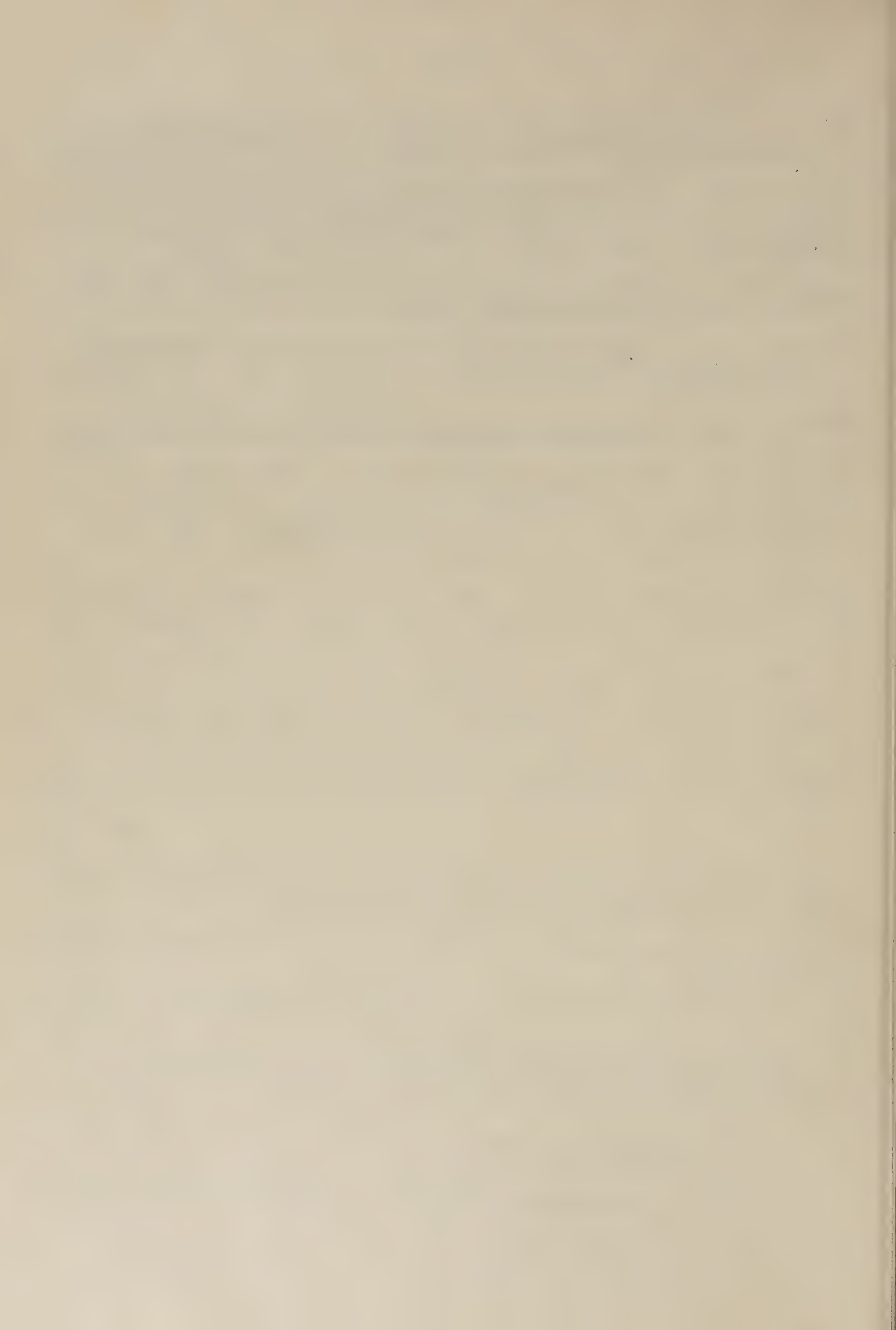
Progress in fishery science is seldom limited by equipment or facilities. Acquisition of large research vessels is often inadvisable due to prohibitive operating cost.

Fishery scientists must evaluate the biases in their methods and analyses. A brief review suggests that the preponderance of errors in fishery science are conducive to over-exploitation.

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P A R T I I I

REPORT OF THE WORKING GROUP ON ENVIRONMENTAL STUDIES
AND MONITORING

by

A. Bakun (Chairman)*

ABSTRACT

The main primary variables or conditions which directly affect individual fish and, through these, the abundance of fish populations are: food, predation, temperature, salinity and oxygen concentration. These primary variables are altered by several processes, some of which are described in this report, together with different sources of information on environmental variability and biological characteristics. There is a need for more rigorous approaches to the problem of environmental effects on fishery problems, and some suggestions are made in this respect. The information on environmental variations is of great value for management purposes, particularly when environment has proven to be a major source of fluctuation of fish availability.

1. INTRODUCTION

Fishermen are very aware that short-term availability of fish is often dependent on environmental conditions such as temperature of the water or state of the tide. In the longer term there are equally important relationships with environmental changes, but the linkages tend to be less clear. The requirement of fishermen and fishery managers is that these relationships be identified so as to enable prediction of catches and of their effect on the abundance and viability of fish resources. For the fishery scientist the problem is a more fundamental one of differentiating between availability and absolute changes in abundance; and of understanding the processes by which various environmentally-dependent rates, such as recruitment, growth, natural mortality and fecundity interact with exploitation to cause negative consequences such as stock dislocation or collapse. The results of the discussions of these and other topics related to the study and monitoring of the environment are summarised in this report. Those who contributed to the discussions and preparation of this report are S. Coombs and F. Robles, who acted as rapporteurs, as well as P. Bernal, J. Cañon, P. Fréon, M.L. Garcia, O. Guillén, R. Jones, R. Jordán, P.M. Kelly, P. Lagos, R. Parrish, G.D. Sharp, P. Shelton, S. Zuta and others.

1.1 Fishery-oceanographic research topics

Lack of understanding of the processes which regulate recruitment, in particular, has been identified as perhaps the most serious problem hindering the advance of fishery science. Studies of historical data bases seem to have been remarkably unsuccessful in finding clear relationships. One argument has been that one would not expect simple or constant relationships. Some relationships that have been found are undoubtedly mere chance agreements with no basis in reality; with a multitude of conceivable environmental effects and relatively short fishery time series, some degree of empirical "fit" to one or another environmental series can generally be found. Clearly, there is a present require-

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ment for a more rigorous approach to the problem, within a firm conceptual framework which will enable examination to proceed in a more scientific fashion. Rational approaches, which are based on understanding of the processes involved, and empirical approaches which depend on analysis of available data series, should be merged so as to incorporate all the available pertinent information. Design of observational programmes, monitoring systems, and experiments should be integrated so that all elements are mutually supportive. Any possible "shortcuts", such as interregional comparative studies or other types of approach should be evaluated and used where beneficial.

Above all, a focus must be kept upon overall integration of the various levels of knowledge developed so as to bear directly on real-world needs. For example, we are presently experiencing perhaps the greatest large-scale ocean anomaly in recent decades, the El Niño of 1983. Despite the wealth of theory and data on effects of such anomalies on, for example, productivity, it is an unfortunate fact that at this time there exists no generally-agreed-upon basis for predicting its effect on recruitment and viability of one of the largest fishery stock complexes in the world, the Peruvian-Chilean sardine, *Sardinops sagax*. On the other hand, accumulated experience and available scientific knowledge are sufficient to indicate increased likelihood of serious abnormalities in such factors as reproductive success, availability to exploitation, etc., during periods of intense environmental anomalies.

The larval stage is often considered to be the most likely segment of the life cycle for environmental effects to strongly impact eventual recruitment. The most promising hypothetical mechanisms are discussed in several recent IOC or FAO reports (e.g. Sharp, 1981; Bakun et al., 1982; SCOR Working Group 67, 1982); thus we have chosen not to repeat any lengthy enumeration here. Also for most of the topics discussed here reference should be made to the Proceedings of this Expert Consultation. Many of the papers presented and discussed at this meeting provide an adequate background to this report.

2. SYSTEM EVALUATION AND DEVELOPMENT OF SCIENTIFIC RATIONALE

Considering the interactions within a defined ecosystem, there will be a different emphasis on the physical and biological forcing functions depending on the nature of the system and the implicit time and space scales of the processes involved. For example, consider a simple contrast between a temperate-shelf sea (e.g. North Sea) and a boundary-current (e.g. Peru Current) system (Table 1). By implication there will be greater changes in hydrography, productivity and geography of the biota in the boundary system than in the temperate-shelf sea system.

Table 1. Some contrasting characteristics of temperate-shelf seas and boundary-current systems

Temperate-shelf sea	Boundary Current
Relatively-closed system Slow biological turnover Locally driven Physically and biologically buffered against change	Relatively-open system Rapid biological turnover Affected by distant physical events Weakly buffered against change

Furthermore an examination of the lifestyle of the fish species will suggest the relative importance of links with other components of its system. An oversimplified example is presented in Figure 1.

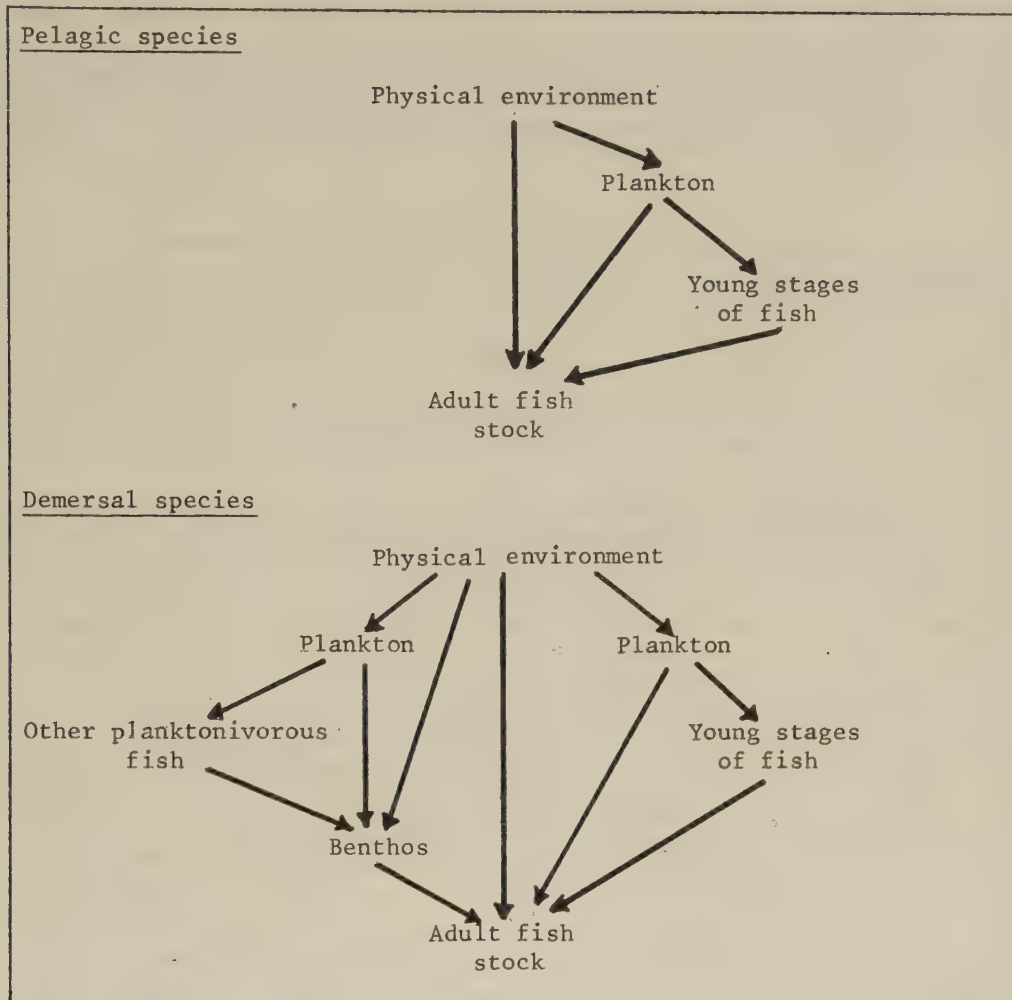


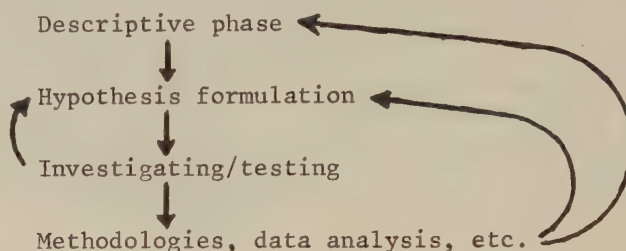
Figure 1. Simplified links of pelagic and demersal species with other components of their systems

Eastern-boundary currents are dominated by pelagic fishes and much of the exploited biomass is composed of species at relatively low trophic levels. Temperate-sea shelf systems tend to be dominated by demersal species; however, they also have considerable quantities of pelagic species. The demersal species typically are at the higher trophic levels and they tend to have complex food webs which interact with, and include, the food webs of the pelagic species. The more direct links between the physical environment and the adult fish stock for a pelagic species of eastern boundary currents suggest that there is less buffering between the response of the fish to environmental change and therefore the effects may be more readily observable.

Clearly a wide range of processes whereby environmental change affects fish populations can occur in most systems. The important consideration is that an appreciation of the relative influence of the system-specific characteristics will enable some assessment to be made of the relative importance of the various mechanisms. Obviously, collecting data sufficient to account for all environmentally-caused variance will not be possible. Focus must be directed toward a single process, or at most a very limited number of processes, having a large enough impact to be discernible through the noise level generated by the multitude of other processes which are occurring.

The range of scales to be considered is wide. For example, the geographical scales of populations can range from hundreds of metres in coral reefs to thousands of kilometres in boundary currents; individual environment scales can range from centimetres (e.g. for larval feeding) to thousands of kilometres (e.g. ambit of an adult fish); relevant time scales can range from one day (for larval starvation) to a couple of years (generation time of populations).

Certainly, it is essential to have a sound conceptual basis upon which to organise any study. The alternative is to expend resources collecting various pieces of information which may never add up to the answers required for necessary actions. Progress is expected to occur as a result of an iterative feed-back process, more or less as follows:



From the formalisation of a hypothesis concerning availability of fish, a logical appraisal should be undertaken following a scheme generally similar to that outlined in Figure 2, where particular research pathways are identified.

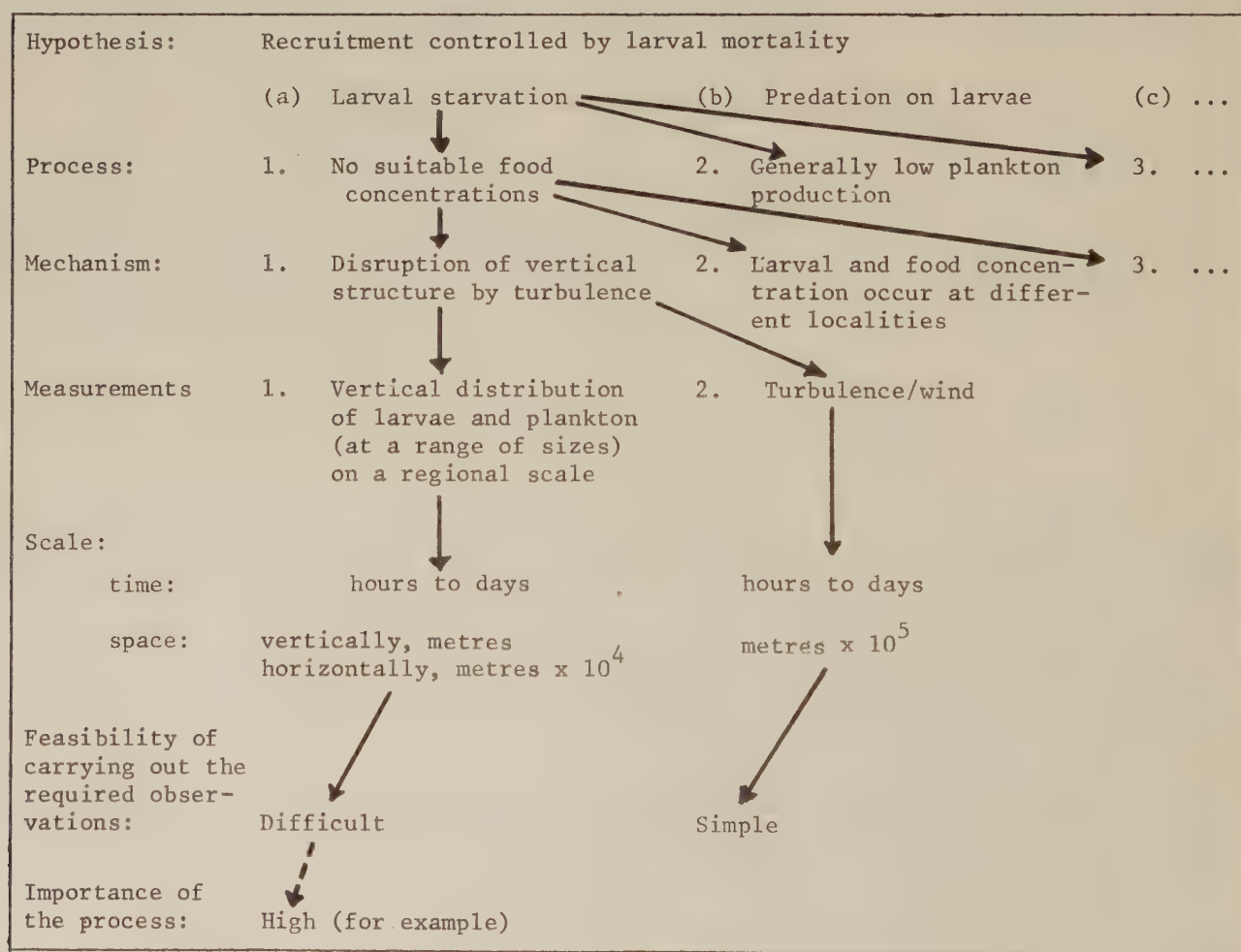


Figure 2. Example of pathways for the appraisal of biological and physical measurements that need to be made when testing the hypothesis that recruitment is controlled by larval mortality.

From this type of analysis we can determine the biological and physical measurements which are to be made. The resulting benefits are efficiency of sampling and improved interpretation of results. Equally, the importance of each process or mechanism can be assessed from a consideration of the system-specific attributes and the feasibility of carrying out the required investigations can be judged; by this means some priority can be assigned to the investigation on a cost/benefit basis.

Complementary to the formalised-hypothesis-testing approach there is still a need for a monitoring function to build up a data base on potentially useful variables. Ease of measurement is of prime importance to ensure continuity in data collection.

3. PRIMARY VARIABLES

In order for a stock to achieve and maintain a large population, a number of physical, chemical and biological conditions must be present on the proper time and space scales. Conditions which directly affect individual fish (i.e. food, predation, temperature, salinity, and oxygen concentration) we are calling "primary variables". In addition to being affected directly by the primary variables, fish are affected indirectly by processes which alter the primary variables (i.e. insolation, turbulent mixing, transport, divergence and convergence). For development and growth to occur food of the right nutritional quality and particle size must exist at sufficient concentrations. In addition, temperature, salinity and oxygen conditions must not only be within the physiological limits of the stock but a correct mixture of these factors must exist. For example, food may be adequate for rapid growth at one combination of temperature, salinity and oxygen concentration but increased physiological stress caused by changes in temperature or oxygen concentration could limit growth. This could occur even when all of the factors were individually within the physiological limits of the stock.

Rapid growth during the early development stages is particularly important in the eventual recruitment of a stock as increased body size is an important factor in reducing susceptibility to predation or cannibalism. In this regard it is noteworthy that a great majority of neritic fishes, including demersal and littoral forms, have epipelagic larvae. Mortality rates of epipelagic larvae are known to be quite high; however, predation on demersal or littoral larvae might be expected to be even higher due to the increased concentration of vertebrate and invertebrate predators in the benthic and littoral regions.

The high mortality rates that characterise the egg and larval stages make these stages likely susceptible periods for environmental perturbations to substantially alter recruitment. However, to date the number of larvae, as measured by extensive surveys, has proven to be a better index of parent-stock size than of recruitment. This, of course, does not mean that recruitment is, or is not, established during the early life history; but it does suggest that recruitment may be affected by environmental conditions that relate to the juvenile or adult segments of the life cycle.

There is essentially nothing known, for a surprising number of exploited fishes, from the time the larvae become mobile enough to avoid egg and larvae survey nets (usually about a month after hatching) until they arrive at nursery grounds which are usually located in shallow water. This "larval drift period" usually lasts for about a month to nearly a year depending on the species. Environmentally-induced variation in growth, mortality or the larval drift pattern are potential factors in recruitment regulation during this period. Recruitment, in many stocks, is considered to be established by the time the nursery grounds are occupied.

Environmentally-related changes in the natural mortality rate of post-recruits obviously cannot be excluded as having great potential to affect population size, particularly when there are multiyear trends in population size. In addition the adult segment of the stock may directly alter recruitment through changes in egg production. For example, feeding conditions could alter the factors related to egg production, i.e. growth, condition factor, age at maturity, batch fecundity, number of spawnings. Large-scale anomalies are also known to greatly alter the location, seasonality, and volume of spawning; the anchoveta response to the 1972 El Niño is a good example of this type of alteration.

4. PROCESSES ALTERING PRIMARY VARIABLES

4.1 Primary productivity

Primary productivity depends on such factors as insolation, nutrients, temperature, circulation and mixing processes, grazing and sinking of phytoplankton. Major productivity centres tend to be found in regions of vertical mixing and horizontal divergence of the upper layers. Turbulent mixing and sinking may adversely affect the rate of primary productivity by removing organisms from the illuminated surface layer. Variation in intensity of coastal upwelling may cause variations in the supply of nutrients supporting organic production in the upper layers.

The transfer of nutrients to the surface layers is not only dependent on upwelling strength (vertical velocity), it also depends on the nutrient content of the waters at the depths at which the upwelling originates. For example, in the Peru current during El Niño occurrences the nutrient-poor surface waters may extend to greater depths and the upwelling process may not be deep enough to reach high nutrient concentrations.

There is a possibility that changes in species composition in the plankton community may be important in determining availability of suitable food particles. During the 1976 El Niño, for example, dinoflagellates were dominant off Peru where normally diatoms are dominant.

4.2 Pattern formation and destruction

The spatial variation of food is known to be extremely patchy, and micro-scale patchiness is thought to be a significant factor controlling recruitment of fishes. The development and dispersal of physical microstructure is related to various processes including solar insolation, tidal currents and wind-induced turbulent mixing. Insolation alters the micro-structure by decreasing the density of the surface waters, resulting in the development of vertical density gradients. On the continental shelf and other shallow bank areas, turbulence generated by tidal flows can destroy vertical stratification, resulting in frontal formations between stratified and mixed zones. Wind-induced turbulent mixing, which is proportional to the cube of the wind speed alters patchiness by dispersing vertically stratified physical and biological microstructure, by bringing nutrients into the upper mixed layers. and by altering the salinity, temperature and oxygen concentration in the surface layer.

4.3 Transport

The epipelagic phase of neritic fishes varies from only the early life history phase in many demersal and littoral fishes, to the whole life cycle in the case of many small pelagic fishes. The epipelagic zone generally contains appropriate food for fish larvae; it is also the area where transport is the largest. Thus, in addition to the problems of securing sufficient food for early growth and of avoiding predation, larvae must also be located in a geographical position which favours larval transport to nursery areas where a new combination of food, physical, and chemical conditions may be required for juvenile growth.

Transport in the ocean may involve one or several flow mechanisms. The large-scale geostrophic currents are related to pressure gradients which can be estimated from the ocean temperature and salinity structure and which may be associated with sea-level variations at coastal stations. Surface Ekman transport is directly driven by the local wind; upwelling regions are characterised by offshore-directed Ekman transport which may affect recruitment by offshore dispersion of larvae. Oscillating tidal flows can result in net transport over a number of cycles, particularly if organisms can adjust their depth level at different phases of a cycle or even cling to the ocean bottom during unfavourable flow phases. Vertical shear flows of various types are common in the ocean; vertical migratory behaviour may be adapted to utilise vertical variations in horizontal flow. Various surface skin effects, Langmuir circulations, nonlinear surface wave transports, etc. might also be involved in crucial life-cycle transport processes.

4.4 Large-scale anomalies

Anomalies in atmospheric circulation strongly influence the ocean. There are indications that the upper ocean and the atmosphere are closely coupled over extensive areas from short- to long-term climatic time-scales. The air-sea coupling is accomplished by atmospheric forcing in the ocean. The effects of these interactions appear in the ocean's thermal, velocity and salinity fields, which are affected by the winds and the temperature in the lower atmosphere.

El Niño is a good example of large-scale air-sea interaction and primary variable change by environmental conditions. Anomalous behaviour of the southeast trade winds in the central equatorial Pacific generates a large-scale perturbation in the upper ocean in the form of equatorial Kelvin wave, which propagates eastward, and deepens the thermocline along with the intrusion of equatorial surface waters of higher temperature and low salinity toward the west coast of South America. The effect of the anomalous water and deep thermocline is to produce large fluctuations in all of the primary variables over a very large proportion of the Peru current region.

5. OBSERVATIONS OF ENVIRONMENTAL VARIABILITY

Some of the most common means of acquiring information and monitoring environmental variability are:

Maritime observations. As part of the global weather reporting network, commercial ships generally record sea-temperature, surface-wind, and other atmospheric measures.. These observations provide basic data on the state of the marine environment. The cost to fishery programmes is low because their use for fisheries is a byproduct of meteorological programmes. In fact, the incorporation of these observations into large-scale analysed fields by the meteorological agencies offer a resource for fishery applications such as indices of wind-driven Ekman transport, wind-generated turbulent mixing, and locally wind-produced upwelling.

Shore stations. Observations taken regularly at coastal installations offer valuable and cost-effective means of monitoring the coastal marine environment. Sea-level measurements can be a particularly useful data resource, providing signals of important ocean processes including alongshore flow, water structure, and propagating ocean disturbances such as appear to be involved in El Niño-type anomalies. Longer-period sea-level fluctuations are samples of a fairly large spatial scale, which is an advantage in interpretation. Sea temperature measurements are also very cost-effective signals of ocean variability, but may sample a more local spatial scale. Coastal sampling of other ocean properties, such as salinity or dissolved oxygen (at depths below the surface), may offer very favourable cost-benefit ratios under certain circumstances. Measurements of wind at exposed coastal locations are also valuable data resources.

Ships of opportunity. It is sometimes possible to avoid some of the high cost of dedicated scientific vessels by utilising commercial ships in collection of specialised data. For example, expendable bathythermograph (XBT) systems allow a measurement of subsurface temperature structure without impeding the travel of the ship in any way. XBT observations are collected and disseminated world-wide by the IGOSS programme of the Intergovernmental Oceanographic Commission.

Research vessels. Dedicated ships represent a rather high-cost mode of data collection. However, they may offer the only means to obtain high-quality data on the time- and space-scales required. Hydrographic surveys yield the quasi-synoptic geostrophic current pattern and three-dimensional coverage of ocean temperature, salinity, oxygen and density structure. Towed sensor systems such as undulators or batfish offer a means to measure short-scale vertical or horizontal pattern. A variety of special purpose measurements may be practical only from a dedicated vessel.

Aircraft. Wide areal coverage in a nearly synoptic time-scale can be achieved with instrumented aircraft. Measurements of atmospheric variables such as wind, air, temperature, and humidity as a function of altitude can be obtained. Techniques are available for remote sensing of SST (sea-surface "skin" temperature) and areal distribution of near-surface chlorophyll. Subsurface temperature structure can be observed from airborne XBT systems.

Satellites. Remote sensing of SST with infrared and microwave imagery has been developed intensively. The absolute accuracy is not presently adequate for defining long time-scale variability of temperature; however, satellite pictures are useful for detecting surface frontal formations and other spatial patterns. Development of descriptors and parameterisations of satellite-sensed spatial pattern that would illuminate longer time-scale variations in pattern-related processes would be very useful to fishery-environmental studies. Chlorophyll concentration can be sensed with high spatial resolution and is expected to prove useful as the technique is developed. Remote sensing of sea-surface properties is limited by availability of cloud-free skies; however, information on cloud cover may be useful for estimating solar radiation reaching the sea-surface in particular areas, although estimates of precision of indications of longer-scale variations are not presently available. Further development of satellite altimetry may yield important information on variations in sea-surface topography and related geostrophic flow. All remote-sensing applications require ground-truth data for absolute calibration; however, for many studies relative indices are adequate.

Historical techniques. As well as current day sampling of biological systems, Some data can be gained from dendrochronological studies (e.g. tree rings) which give a past history of climatic influence. Direct evidence of the response of fish populations is available from fish scale or otolith deposits in marine sediments.

6. BIOLOGICAL SAMPLING

Biological sampling programmes generally involve substantial resource outlays and therefore are not appropriate at all scales and under all circumstances. However, obtaining insights into the actual interactions of life-cycle events with food organisms, predation, cannibalism, etc., on the scales on which they actually occur, is certainly a crucial requirement for progress on the recruitment problem.

6.1 Broad-scale plankton surveys

These provide measurements of the standing crop of phytoplankton and zooplankton, usually by means of various indices such as particle counts or chlorophyll a concentration. Because of the inherent generalizations of broad-scale sampling only major patterns will be detected and only simple or clear-cut relationships with recruitment or adult availability will be found. Concurrent measurement of appropriate simple physical and chemical variables (e.g. temperature, salinity, nutrients) should be made as these may provide more easily obtained analogues of the broad-scale biological distributions.

Biological sampling should be designed to properly integrate the patchy distribution of planktonic organisms. Analysis of the samples to species level is often not required but some estimate of zooplankton size structure and feeding mode (herbivorous/carnivorous) is beneficial; such information allows the calculation of predation pressure on larvae and availability of food for juvenile and adult fish. In this context attention should be paid to coelenterate tissue which is generally indicative of predatory organisms.

For the purpose of broad-scale biological sampling, conventional plankton net tows are usually suitable. However, some savings in both ship and analysis time can be made by using continuous plankton filtering or size-particle analysis using undulating towed vehicles. These instruments offer the additional considerable advantage of taking a concurrent range of physical measurements (also chlorophyll a) at a fine spatial scale. In areas of coherent hydrographic structure it may be fruitful to use some estimate of larval morphometric and histological conditions to determine favourable biological and physical conditions for feeding.

6.2 Fine-scale sampling

Sampling problems are more involved at fine-scales but should receive significant attention in view of the potential importance of the processes taking place. Of particular importance is the vertical stratification of plankton and fish larvae since variability is typically several orders of magnitude greater in the vertical than in the horizontal dimension; thus vertical migratory behaviour of fish larvae may increase their access to favourable food concentrations.

As well as obtaining a finer scale of standing crop measurements fine scale sampling can be integrated with measurements of primary production (e.g., C^{14} uptake) and some quantification of secondary production (e.g. copepod growth rates). Additionally larval fish experiments can be used as direct quantifications of the suitability of the environment for larval survival.

Fine-scale sampling techniques may involve conventional net systems but depth-stratified systems such as pumped samplers or Longhurst-Hardy Plankton Recorders offer great advantages. Particle counter analysis can provide a rapid means of measuring fine-scale vertical distribution; however, some attention should be paid to species or type composition of the plankton to allow for prey selectivity of fish larvae.

6.3 Egg and larval surveys

Sampling for eggs and larvae is sometimes routinely carried out for stock estimation. Valuable interpretive information can be obtained if relatively simple concurrent measurements are made of other biological and physical properties. Normally, a representative sample of plankton other than fish eggs and larvae can be obtained from the same tow taken for surveying ichthyoplankton. This provides information on broad-scale plankton abundance and distribution for general feeding and predation assessment.

In view of a number of reports of juvenile fish being abundant in the neuston, some attempt to refine neustonic sampling techniques is desirable where significant mortality of the juvenile stages is proposed as a mechanism determining recruitment.

7. DATA INTEGRATION

It will nearly always be possible to assemble some amount of data on environmental variability. This amount will always be limited in quantity and quality by the realities of feasibility and cost. The key problem is to find ways to derive the type of information needed (e.g. for fishery management) from the data that may be available (monitored environmental properties, etc.).

One crucial aspect is the integration of data corresponding to various time and space scales. For example, it is generally useful to combine long time-scale, low-spatial resolution information with short term, high resolution information. As an example we can think of recruitment as the outcome of biological processes occurring at short time-scales and small space-scales, i.e. egg, larvae and juvenile survival rates are controlled by the availability of food which is distributed in patches or micro-layers and by the density of predators. However, what might be important for a successful year-class to develop could actually be the relative availability of local high quality pieces of environment at a scale commensurable with the areal distribution of the spawning of the species. For the prediction of recruitment success, therefore, the definition of the quality of the small-scale environment assimilates to an intensive property and their relative availability to an extensive property of the system. As mentioned before, the properties to be measured are likely to be system-specific, although some analogy between similar systems in different geographic localities is expected.

The conversion of these measured properties to information relevant to fishery management, depends on identification of the nature of the causal linkages involved. This will either be on a rational basis, where sufficient mechanistic understanding is available, or on an empirical basis. In general, some combination of rational and empirical approaches will allow the greatest amount of available knowledge to be utilized.

When employing an empirical approach it is essential to recognise the difference between exploratory data analysis and hypothesis testing. In an exploratory data analysis the available data is used to formulate a "model" which describes the observed data; the resulting model is at that point an untested hypothesis, requiring additional data for verification. Hypothesis testing, on the other hand, is directed toward describing the ability of the model to predict outcomes that may not have been observed; it depends on an *a priori* definition of the model which is independent of the test data. Thus a large portion of published fish-stock-environmental relationships are really untested hypotheses and it is not surprising that they may fail when subjected to new data. This is not to

say that exploratory data analysis is not a useful research activity; however, it should not be mistaken for hypothesis testing even though the statistical descriptors may appear to be similar.

In the absence of well-defined causal relationships the simplest exploratory approach is that of correlation studies. These have proven useful for identifying potential causes of changes in recruitment, however, they are limited in scope for several reasons. First, in order to obtain significant results, long-term series of data are needed; unfortunately fishery data series are characteristically short. Second, despite the fact that correlation techniques provided an objective basis on which to judge the results, unrestricted testing over the same set of data actually restricts very severely the actual number of degrees of freedom available for comparisons (multiple testing). This problem has often gone unrecognised and has given "significant" results that are formally incorrect.

Because it is likely that the variables being monitored will have some effect at different scales and may not have immediate effect on recruitment, it is advisable to employ cross-correlation methods that preserve their functional relationship with time, making allowances for the expression of time-lagged responses. For example, intense coastal upwelling upstream of, and preceding, spawning activity could be a favourable larval survival factor in its effect on abundance of appropriate food organisms; however, it could be an unfavourable factor if it occurs during the peak of spawning where it could result in lack of proper food organisms and in offshore dispersion of the larvae themselves.

At times different environmental or biological processes exhibit variability on distinctly different scales; if these are not separated (by filtering, etc.) the analysis may be hampered by interference and smearing among different processes. Certainly, failure to separate obvious scale differences that appear in data sets will result in loss of valuable degrees of freedom in the shorter scale components due to autocorrelation imposed by longer-scale components. One useful exploratory data analysis technique is spectral analysis, whereby historical information can be used to explore how total variability is partitioned among different time or space-scales.

It should be noted that it is not necessary that a causative process has the same dominant period of variation as the affected variable. (For example, one need not necessarily look for an environmental property with a 40-year period of variation as an explanatory variable for the two periods of high Japanese sardine catches.) Effects tend to "cascade" from shorter to longer scales. One or several short-lived storms during peak spawning periods might disrupt a year's recruitment; several strong or weak recruitments might determine long-term viability of an exploited stock.

Various exploratory data analysis techniques are available. The main point here is that they basically involve searching for relationships and structures within a set of observed data and exhibiting them in a compact and recognisable manner. In order to draw well-founded inferences about situations not in the observed data set, or those which have not yet occurred, it is necessary to shift the point of view toward hypothesis testing. Thus it is necessary to define *a priori* the functional relationships to be tested, hopefully based on fundamental principles or at least following a well-defined, explicit model or rationale laid out beforehand. In this sense it is more important to have at hand a well-defined rationale on how different processes are related, even if some of the details have been deliberately simplified, than to try every plausible relationship or alternatively to formulate complex models which have parameters that are difficult or impossible to measure accurately.

A goal of environmental studies is to provide a basis for the formulation of predictive models. At this stage, robustness of models must be given high priority. The systematic application of the simplest functional relationship, almost conceived as a null hypothesis on which to contrast results, will provide the foundation on which to build upon. First order approximations and linear theory should be applied and their explanatory and heuristic possibilities exhausted before proceeding to more sophisticated formulations. This recommendation follows from the fact that neither the relationships linking the different system components, nor the variability (stochasticity) of variables are well enough understood to warrant other approaches.

The distinction between the dependence of small-scale variability of the environment on larger scales as distinct from the effect of both upon the biosystem (or subsystems), is of paramount importance. Parameterisation on a larger scale is often used to describe variability of a smaller scale process. The selection of variables to use will very often depend on system-specific characteristics: i.e. coral reefs, shelf systems and eastern boundary current systems, might require different sets of variables. Parameterisation of environmental variables should be based whenever possible on realistic physical or biological mechanisms. This is particularly important with variables where a single measurement, such as wind, could represent completely different processes depending on the choice of functional relationships parameterised. For example, characteristic Ekman transport over a given time period would be properly formulated as being proportional to a vector average of the wind velocity raised to the second power, whereas turbulent mixing energy added to the water column would be formulated as a scalar average of the wind speed raised to the third power.

Given the nature of the problem, with important processes taking place on different scales, development of parameters that could integrate extensive properties (large scale patterns of relevant variables) with intensive properties measured at a local scale ("quality" of local environmental) may be crucial to effective modelling efforts.

8. EXPERIMENTAL EFFORTS

The requirements of experimental studies are of a different nature than those of environmental monitoring. They are specifically designed to test a hypothesis explicitly formulated. Consideration of the accuracy and precision of the variables to be measured with respect to the expected changes of the dependent variable is a prerequisite. Very often this implies the development of new sampling gear or laboratory techniques. For example our limited knowledge on juvenile or pre-recruit survival rates is basically due to the inadequacy of available sampling gear. Progress in this area will undoubtedly result in an increased explanatory ability.

Because of restrictions imposed by practicality and precision, field experiments will be focussed on small to medium-scale processes affecting individual survival (i.e. egg, larvae and juvenile survival), and on how these are influenced by short-term environmental changes. The research goal is to recognise and predict the quality of the environment on a local scale on some quantitative basis. The effects of pattern formation and destruction, mixing, and stratification are areas that can be studied in the field making full use of current technology.

A special area on which field experiments can be of great use, refers to the calibration of "proxy" environmental variables. Short term, high resolution field studies are particularly useful for understanding the mechanisms by which a global variable, that may in itself incorporate different types of information, will be manifested at a certain scale. For example, observations of the variation of the depth of the mixed layer could help to calibrate time series of the wind to describe turbulent mixing. Detailed hydrographical surveys could serve to intercalibrate time series of sea-level observations from tidal stations at the coast. Ground truth measurements of chlorophyll are needed to calibrate synthetic chlorophyll estimates from satellites.

A necessary complement to field studies, and sometimes a required pre-requisite, are laboratory studies. Here the emphasis is upon the explanation of causal mechanisms through the manipulation and control of environmental variables. In particular, measurements of rates is a goal frequently reserved for laboratory studies. The definition of the physiological requirements of the different stages of the early life history can be studied in the laboratory. This in turn provides meaningful information for identifying areas of the environment suitable for the organisms. Rates of feeding, the effect of the quality of food (particle size, specific composition) are well suited for laboratory experimentation. Other rate processes such as rate of predation and cannibalism are potentially suitable for laboratory experiments.

9. COMPARATIVE STUDIES

Intercomparisons among different regional systems exhibiting similar environmental dynamics and similar fish population assemblages may be sources of additional information. The costs of such studies may be limited to acquiring or exchanging data that may already have been taken in the various regions. Such comparisons may provide a firmer basis for evaluating the validity of transferring experience of fishery events in one region in order to predict outcomes of actions taken in another.

In addition, to the extent that closely-related species function as analogues, pattern recognition among seasonality and geography of spawning habits and environmental processes may yield information on the crucial mechanisms controlling reproductive success. Since natural selection implies accommodation of reproduction strategies to the most crucial environmental factors, compelling patterns of correspondence suggest important causal linkages. Such information might serve to aid in choosing a strictly limited set of explanatory variables so as to make best use of limited degrees of freedom available in recruitment time series.

Finally, these studies may be useful in building statistical confidence in weak empirical relationships. We have noted that high correlations are not expected between recruitment which is affected by many environmental mechanisms acting on various scales at various life-cycle stages, and any one environmental variable. Empirical relationships which have the same general form in several independent regional systems would, on the assumption of analogues, acquire increased statistical significance. In fact, subjecting any empirical relationship to the discipline of inter-regional comparison would appear to offer some useful guidance as to validity and generality.

10. STOCK AND RECRUITMENT

Implicit in the requirement for recruitment information for fisheries management is that there is a relationship between spawning stock size and eventual recruitment such that at some population level recruitment overfishing may occur. Identification of the form of this relationship, particularly the point at which recruitment is reduced, is, therefore, of great interest. However, there is considerable dissatisfaction with the concept of fitting of a single time-invariant "stock-recruitment curve" to a pattern of data points which exhibits a great amount of "environmental" scatter and may contain substantial serial correlation.

It has been suggested that a family of stock-recruitment curves, representing a range of environmental situations, may be a more satisfactory way to approach the issue. This family of curves may look like those in Figure 3, where R represents recruitment due to spawning of a parental stock size, S , and e_i represent various environmental states.

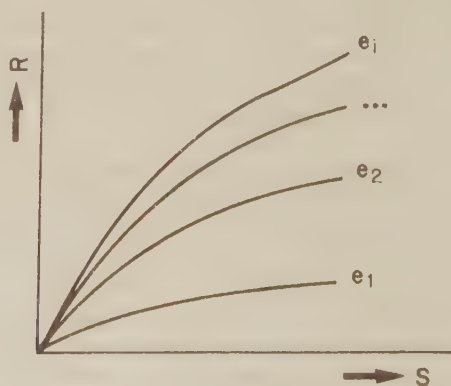


Figure 3. A family of stock-recruitment curves

Heuristically, this makes very good sense; however, the problems in properly fitting a family of multi-parameter curves to a very limited number of actual data points, in a purely empirical manner, are formidable. There is substantial danger of generating pure nonsense by non-judicious use of such a procedure.

One way to objectively fit such a family of curves is by means of a multiple regression in which stock size may appear as one explanatory variable with one or more environmental variables. For example, the formulation:

$$\ln(R/S) = a_0 + a_1 S + a_2 e_j + \dots$$

will generate a family of "Ricker-type" curves for constant values of the environmental variable(s), e . Note that e_j could also represent a multispecies effect, e.g. the size of a predator stock, etc. Note also that this particular formulation represents a multiplicative model; i.e. the explanatory variables impact recruitment in linear proportion to the potential recruits present, rather than affecting absolute numbers as such. Such a multiplicative model would be appropriate for processes such as adult cannibalism on larvae by non-selective filtration of a portion of the water volume occupied, loss of a fraction of potential recruits by offshore dispersion, starvation or growth-dependent predation loss due to inadequate food particle availability, etc. Where other types of mechanisms operate, e.g. where limited habitat space may be filled by potential recruits or larvae may be abundant enough to substantially alter their ambient food supply, different (e.g. additive rather than multiplicative) formulations may be more appropriate.

Note that this example is only one of a range of possible formulations, the determination of which depends on the particular mechanisms involved. Further, it should be emphasised that, before much credence is assigned to the form of any apparent density dependence which may emerge from a fitting procedure of this type, two conditions must be fulfilled. First, the relationship to stock size must represent a substantial portion of the explained variance. Second, there must be a high degree of confidence that the environmental portion of the relationship is realistically modelled, thereby ensuring that the form of the stock dependence is not controlled by possible uncertainties in the environmental dependence.

Of course, situations where there are only two, or at most several, well-defined and separate environmental states (e.g. El Niño vs. non-El Niño vs. Anti-El Niño etc.) with corresponding separate clusters of data points on the stock recruitment diagram, it may be possible to directly fit separate curves.

However, it should be re-emphasised that models produced by purely empirical fitting procedures constitute exploratory data analyses, which are merely descriptions of the data already at hand. Their ability to yield information on possible situations not yet observed should be regarded as an untested hypothesis. Such an analysis can be regarded as a useful predictor only when the variables incorporated do indeed represent the dominant causative mechanisms.

11. CONCLUSIONS

a) There is a requirement for a more rigorous approach to the problem of environmental effects on fishery problems. Because of the complexity and number of possible inter-relationships between the physical and biological aspects of an ecosystem, it is essential to have a sound conceptual basis for research activities. Simple searches for correlations with available environmental data series are likely to be unrewarding in the long run.

b) The benefits of supporting observational programs with experimental efforts and laboratory studies may be substantial. Interregional sharing of results and comparative studies may also be beneficial.

c) The ability to forecast effects of environmental anomalies on recruitment is an important goal. However, lacking this ability, the simple knowledge that an environmental anomaly may be present is useful in itself as a possible motivation for conservative management strategies or preparation for short lead-time adaptive management actions.

- d) Valuable information on environmental variations may be obtainable at relatively low cost from maritime reports and from regular measurement of sea level, sea temperature, and wind at exposed coastal locations.
- e) Understanding of processes operating at a scale commensurate with feeding and survival of fish larvae may be a key to understanding recruitment variation. Important advances may accrue from development of plankton sampling capable of resolving fine horizontal scales and the even finer scales associated with vertical structure of fish larvae, and planktonic food and predator organisms.
- f) Care should be taken that empirical analysis procedures are appropriate; high value should be placed on ensuring statistical robustness of conclusions. Processes should be addressed on the scales at which they are acting, or dependence on larger scales should be parameterised according to a well-defined model of the linkage between scales.
- g) Focus should be kept on integration of the various levels of knowledge which may be developed so as to bear directly on real world management concerns.

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P A R T I V

REPORT OF THE WORKING GROUP ON SOCIETAL IMPLICATIONS
OF VARYING FISHERY RESOURCES

by

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ABSTRACT

This report identifies the different effects the variability of fisheries resources has on society, the different groups (at individual, national and international level) which play a role in the decision-making process, and those sectors that are more seriously affected by resource fluctuations. The report also discusses the development of some fisheries in the past, sources of problems related to fisheries management, the participation of fisheries scientists in the decision-making process, the problems that confront fisheries scientists in this process, and suggests some remedies for dealing with such problems.

1. INTRODUCTION

Neritic fish populations are of great importance to the many countries that exploit them. They serve as a source of food or as a source of feed supplement in the form of fishmeal. Used as exports, these fish products may earn substantial foreign exchange. Pelagic fish populations, in particular, exhibit wide fluctuations in abundance over time (e.g. Tanaka, 1983; Parrish et al., 1983; MacCall, 1983). Such unpredictable sharp changes in the biomass make it difficult to development management plans that seek to maintain high and sustained yield or benefits while at the same time ensuring the preservation of the resource. Scientists in many regions of the world have been concerned with these fluctuations, how to predict their occurrence, and how decision-makers should respond once a catastrophic event in fisheries is imminent. Geophysical and biological fluctuations also lead to fluctuations in the societal benefits that may be derived from the exploitation of fisheries resources. This, in turn, makes it difficult for policy-makers to put in practice national development plans based on potential long-term contributions from the fishing sector. These are some of the reasons why this particular Expert Consultation was convened and why this Working Group was requested to look into the societal implications of the variability of fishery resources.

This report presents the contributions of a working group that was set up to review the societal implications of varying fishery resources. Major contributions to the discussions and to the drafting of this report were made by R.J.H. Beverton and A. Gummy, who acted as rapporteurs, and by B. Brown, D. Butterworth, J. Cañon, E. Kwei and others. The report is divided into five parts: possible causes of fluctuations of neritic pelagic fish; a general description of the implications for society of fluctuations in fish catches; a general discussion about how some fisheries developed in the past; the participation of fisheries scientists in the decision-making process at national and international levels, including problems that confront fisheries scientists in the decision-making process and some of the sources of, and suggested remedies to, these problems. The report concludes with a set of recommendations.

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The report is presented in general terms and not all examples apply to each and every fishery. It is also important to note that different characteristics of political, economic and cultural systems often foster different approaches to fisheries management, and that similar approaches can have different implications in these varied political, economic and cultural systems.

2. FLUCTUATIONS IN FISH CATCHES

An important characteristic of fish populations that affects society is that they exhibit large fluctuations in overall abundance, which affect catches obtained by man (and other predators). These fluctuations seem to be larger in pelagic neritic fish populations. In the past, when pelagic fish populations have declined sharply, a debate ensued as to whether the decline resulted primarily from fluctuations of the environmental factors or from overfishing. Those who believed that fishing pressures were responsible contended that the fish population would probably have been able to cope with fluctuation in its physical environment in the absence of heavy fishing activity. Others contend with equal conviction, and often with equally convincing pieces of scientific information, that the sharp decline in landings resulted primarily from changes in environment. Usually, both heavy fishing and environmental changes are involved in the collapse of fisheries. It is not surprising, however, that these debates tend to remain unresolved, as participants in the debates tend to adhere to one view or the other. In the recent past there have been several declines in pelagic fish catches in such fisheries as the Californian Pacific sardine, the Peruvian anchoveta, and the South African and Namibian pilchard. Murphy (1977) has identified other clupeoid populations that have shown drastic declines in catches: Hokkaido-Sakhalin herring, Atlanto-Scandian herring, Downs herring and the Japanese sardine. At this stage of our scientific knowledge, and as long as perceptions of the issues remain polarised, it is not at all certain that this debate will ever be resolved to the satisfaction of either of these groups. A third group has emerged that considers both factors to be about equally important in the demise of such fisheries. The arguments presented in these contending views notwithstanding, there is no instance as yet of the collapse of a fishery under conditions described as light exploitation. In addition, each of the fisheries that has witnessed sharp declines in landings (Californian Pacific sardine, Atlanto-Scandian herring, South African and Namibian pilchard, and Peruvian anchoveta, among others) has been advised to reduce fishing effort before its respective collapse.

Other sources of variability in fish landings relate to the fluctuations that occur in international and national political and economic systems. Even if members of the international community are not directly involved in the exploitation of a national fishery, the fishery will be affected by factors that originate in other nations. Such factors can affect the supply of fish and might include, for example, transfer of technology (including technical advisers), changes in policies related to free access to coastal resources, need for foreign exchange, and loans from international development agencies. They can also affect demand for fish products, and might include such factors as international market demands, competition from other fisheries, and international commodity prices for fish products. A third set of factors might not appear to relate directly to fishery management, but in fact can have a major impact on the fishery, for example, the expropriation of foreign investment in sectors other than fishing, and international conflicts in general.

National factors affecting the fishery can centre around changes in government and/or changes in governmental personnel in a variety of ministries. Other national factors can include conflicting objectives pursued by various groups in society, many of which are not directly involved in the fishing sector. It is important to remember that the fishing sector is but one subsystem embedded in a larger political and economic system. In addition the fishing sector, too, is a complex system, the competing members of which may have different objectives.

In the two sections that follow, discussions are presented about how a typical fishery develops and declines. These are developed in reverse order, with the typical decline presented first, as it is the societal implications for that phase which are less well understood.

3. SHARP DECLINES IN FISH CATCHES

This section briefly describes in general terms how a typical society might be affected if fish catches became sharply reduced, in a relatively short period of time, regardless of cause. While the brief description that follows may appear to be a simplistic representation of a relatively complex process, it serves to suggest to decision-makers (not just those involved in the fisheries) that sharp declines in fish catches can have widespread societal implications. The impacts mentioned in the following paragraphs have been taken from the history of one or more of the pelagic fisheries that have recently undergone either a sharp decline in productivity or a collapse.

First, it is important to note that there can be minor fluctuations in fish catches as well as major sustained declines. Temporary declines in fish catches can, for example, lead to bankruptcies of marginal producers and of those in the fishery who are heavily in debt (boat-owners, processing plant owners, etc.). Some observers view this adjustment as an economic rationalisation of the fishing sector while others view it as an increasing concentration of capital amongst a declining number of industrial firms. Temporary unemployment often follows, foreign exchange earnings may decline (or may increase with short-term jumps in prices due to shortages of that product), and some foreign investment may enter the fishery. Minor declines in landings have in general minor adverse aggregate effects for society, even though they may have major effects for individuals within the society.

Relatively major sustained declines in fish catches, however, cause more profound social, economic, and political dislocations. These dislocations will not be confined to the fishing sector but will spread like ripples throughout various sectors of society. For example, bankruptcies of the seemingly stable larger fishing firms lead to financial difficulties, including an inability to repay either bank or government loans, in industries that support fishing activities, such as boat construction, gear and net manufacture, etc. Crewmen are released by boat-owners, while factory workers are released by owners of processing plants and other industries as well. Some of the unemployed workers will emigrate (with or without their families) to other larger cities where they believe chances for employment will be higher. In some instances, layoffs of crewmen and factory workers lead to labour unrest and possibly to worker or union demands for government support in these crises, including financial assistance until the end of the crisis. (An extreme but not atypical example of pressure that decision-makers might have to face, is when workers occupy their factories until their demands for government assistance are met.)

In response to increasing layoffs of workers and fishing crews and to related unemployment problems, governments may find employment for some of the unemployed in other sectors of the economy or on public works projects. Often this will be at the government's expense and in time may prove to have provided either no more than a delay in confronting labour unrest or a shifting of labour unrest from one sector to another. Changing jobs also means a loss in human resources (accumulated training and knowledge) and a need for the retraining of these employees either voluntarily or with government assistance.

For the government, a decline in fish landings will be accompanied by a loss of foreign exchange, and perhaps a need to renegotiate foreign loans and a disruption (e.g. a delay or cancellation) of regional or national economic development plans that were dependent on the earnings from the fishing and related sectors. There will also be a need to meet contractual obligations that had been made months earlier and had been based on anticipated landings. The apparent instability in the availability of the resource could lead to loss of markets as buyers search for alternative supplies of the same product or for substitute products. This was the case with the sharp decline of the Peruvian anchoveta catches in the early 1970's which stimulated the production of soybeans and amino acid supplements, mainly in Brazil and the U.S.A., as substitutes for fishmeal in animal feedstuffs.

With a sharp decline in pelagic fish catches, there tends to be an even greater concentration of capital in fewer fishing companies, as even some of the larger producers go out of business. Many of the larger industries that do survive either had diversified their financial investment before the collapse or, if not, tend to diversify after the collapse by investing in other sectors of the economy in order to hedge against the

financial impact in the future of similar declines in fish catches. In some instances, bankrupt businesses may fall into the hands of the government, which may have guaranteed the loans to industry and fleet-owners during the development phase of the fishery, in order to stimulate investments. In other instances, nationalisation of the fishing sector or massive subsidies to the surviving industries may take place. In still other instances, sharp declines in fish landings can lead in time to government denationalisation of the fishing sector, if the fish populations remain at relatively low levels (e.g. "reprivatisation", as in the Peruvian situation in the mid-1970's, when the fleet, but not the fishmeal processing factories, were denationalised).

In a developing country the impacts of a sharp decline in fish catches can have catastrophic long-lasting societal effects, whereas in developed countries the societal impacts of stock declines may be more easily absorbed by other sectors of the economy. This is especially valid when the developing country is dependent for the financing of many of its development programmes on the foreign exchange derived from its fishery or when its fishery is dependent on the exploitation of one major fish population as opposed to a truly multispecies fishery.

Finally, as witnessed in most recent pelagic fishery collapses, sharp declines in fish catches are usually followed by calls from many quarters for improved and costly scientific assessments of fish populations as well as of the environmental factors that might affect them, as there seems to be no clear consensus about what the primary cause for the sharp decline had been. In addition, each sharp decline or collapse has been followed by a plea, always too late, for an economic rationalisation of the industry, as well as for increased regulations on fishing activity.

4. DEVELOPMENT OF A TYPICAL NERITIC FISHERY

This section presents a brief, general description of how a typical fishery develops, with some emphasis on pelagic fisheries. Again, it is important to note that this description will not match exactly the historical development of any single pelagic fishery but instead represents a composite of factors taken from the histories of several of them.

Preceding the development of a large fishing industry, there usually exists an artisanal fishery which in most countries supplies fish to local markets, usually for local consumption. As large industrial fishing firms develop, many artisanal fishermen may join the industry and, as a result, less fish is available locally and the costs of what is available begin to increase. In addition, catches of fish by the industrial fleet may reduce the availability of the resource for artisanal fishing activities, or the by-catches of the large fishing concerns may compete with the artisanal catches in the market-place. These problems, among others, cause conflicts between the emerging industrial and the existing artisanal or traditional fisheries.

The growth phase in the development of a large commercial fishery can be divided into two stages. An "early growth" stage begins with awareness of an abundant resource, at a time when there is a growing national or international demand for fish products, and at a time when the national economic or political setting is conducive to tapping that resource (as was the case in Peru in the early 1950's and in Chile in the latter part of that decade). The primary products of interest are usually canned and frozen fish and fishmeal. While it may be true that the canning or freezing industries are very important economically in terms of catch utilisation, fishmeal has exhibited a more dynamic demand in the international market-place. In addition, it is often favoured as a source of foreign exchange.

An accelerating process of expansion in the fishery develops once the basic components of continually increasing demand for fish products (e.g. canned fish or fishmeal) and of perceived abundance of the resource (bordering on limitless) are present. The early growth stage of the fishery development exhibits, in general, the following features:

- There is a rapid increase in investment in vessels and plants, as well as in the necessary supporting infrastructure. Such investment can be national or international in origin. Because the fishery is still in the early stages of development and there is a relatively high level of implied financial risk, financing will not have achieved (as yet) the same dimensions as in the later stage of the expansion process (to be discussed).

- Many unskilled labourers are attracted to the fishing sector, usually drawn away from economically marginal sectors including rural agricultural areas. This process of attraction is exerted region-wide and produces a migration to the areas in which the fishing activities are developing. The urban infrastructure in such areas is often ill-equipped to handle the immigration.

- Supporting (ancillary) industries such as shipyards, net manufacturers, warehouses, food suppliers, etc. appear gradually.

- Modern technologies are brought into the fishery and, because of the inexperience of labourers in using these technologies, their effectiveness at first is relatively low. Sometimes this lack of effectiveness raises questions about the appropriateness of the new technologies for that particular stage of development of the fishing sector.

- The investment process is not an across-the-board proposition that covers all elements in the fishing sector. As a result, conspicuous gaps in investment and time lags between investments in the different elements in the fishing sector appear along the chain of catching, processing, marketing, and supporting activities. These gaps and lags lead to increased costs of operations.

- The fishing industry at this stage is usually a profitable business venture, despite its unstructured, virtually anarchical growth. The cost burdens produced by the lack of experience of the workers and infrastructural gaps within this stage can still be absorbed by the profits derived within the sector.

- Direct government involvement in the fishery at this stage of development is often not evident. The lack of government participation usually reflects the relative lack of importance given to this economic activity by the public sector and the interest of the entrepreneurs in maintaining this as a private activity.

- Air and water pollution increases mainly in the coastal areas. This may adversely affect other potential economic and social activities such as tourism.

- At the end of this stage (the duration of which depends on a number of international and national factors including demands in the market-place and national economic policies and development strategies, respectively) the fishing sector appears to some observers to be the picture of stability. Many of the investment gaps generated during the initial growth process have become filled. At this point, the exact potential of the resource may still be unknown and the fact that it could suffer from the effects of fluctuations in the environment, from the biology of the fish population, or from the socio-economic environment may continue to be ignored; in some cases intentionally.

The "late growth" stage is often dominated by political factors. The sector achieves importance as a major source of foreign exchange and employment, though this varies from country to country. Representatives of various governmental agencies have finally taken cognizance of the new economic and social importance of the fishery. The sector begins to acquire relatively more influence in the decision-making process and the already established (but small) industrial sector begins to recognise the potential role of the government in limiting to some degree the access of newcomers to the resource, thereby ensuring, at least temporarily, a more favourable situation for themselves.

During this stage of the fishery's growth process, the government can exert considerable influence on the fishery's rate of expansion. In general the salient aspects of this phase might be as follows:

- There is an increase in investment in the fishery, facilitated by low interest, long-term loans, "drawbacks", favourable import licenses, favourable export policies, guaranteed foreign loans, and so forth.

- Public investments in port and service infrastructure also increase.

- Existing industries reinvest in the fishing sector.

- New capital from other national and international sectors is infused into the fishery.
- The sector becomes a "magnet" for an ever-increasing number of unskilled labourers.
- There are massive, accelerated inputs of efficient, modern technologies.
- Scientific activities related to stock assessments increase in connection with those resources that are exploited by the fishery.
- The activities in the fishing sector continue to be highly profitable, even though the high debt burden of one part of the industry orients its activity more in terms of meeting its financial obligations than its rational production planning.
- Industry acquires an overwhelming influence in decision-making processes that directly and indirectly relate to the fisheries. The labour sector, too, becomes increasingly organised and begins to assert influence on policy matters related to its interests.

Once the growth phase has reached its peak, the industrial component of the fishing sector, which has now become very influential in the decision-making process, finds itself at a crossroads. Fluctuations in the market-place (i.e. demand and price) as well as fluctuations in various aspects of the national economy (e.g. inflation, exchange rates, balance of payments, etc.) have eliminated many of the economically marginal units (i.e. smaller and/or less efficient) from the sector. This leads to an increasing concentration of industrial capital which tends, among other positive and negative effects, to increase production efficiency through the large-scale coordination of the factors of production. Over-capacity in fleet and processing facilities is acknowledged but not reduced. Because the industry expects state support to neutralise the adverse effects of fluctuations of the national economy, earning expectations of the industry usually remain very high.

At this stage, a politically significant element of the population has become directly or indirectly dependent on the fishing sector. The contribution of the fishing sector to the economy is important for social aspects of economic development. At this point the government begins to solicit (but not necessarily to accept) advice from the scientific community about the fish resource. Also at this time, the conflicting objectives of the various sectors, conflicts that had remained latent during the early growth stage, begin to manifest themselves.

5. FISHERIES SCIENTISTS IN THE DECISION-MAKING PROCESS

The involvement and influence of scientists in the decision-making process clearly varies from one country to another and it can vary from one government administration to the next, especially where the scientific input has not yet become institutionalised. A set of case studies would be extremely useful on how scientists derive their recommendations for decision-makers and how those decision-makers use them in developing fisheries-related policies. Similar studies are needed of how other interested parties, such as the fishing industry or conservation groups, derive their recommendations and how they insert them into the decision-making process. It appears that many of these situations are often discussed anecdotally and are in need of systematic, objective assessment.

There are many international organizations with varying degrees of responsibility for providing advice on the management of fish stocks in different parts of the globe's oceans. The procedural characteristics of many of these organizations are well-documented. What is needed are assessments of whether decisions in these bodies are in fact based on the best scientific information available or are the result of compromise between participants (e.g. science by consensus). Some observers strongly believe that much of the maneuvering in such organizations is in manipulating the information to suit the needs of particular interest groups or nations. Do the institutional arrangements match the needs of the fishing communities and the national decision-making bodies?

Among developing countries, there also exist regional forums (Fisheries Committee for the Eastern Central Atlantic (CECAF), Permanent Commission for the Southeast Pacific (CPPS), General Fisheries Council for the Mediterranean (GFCM), Indian Ocean Fishery Commission (IOFC), Latin American Economic System (SELA), Western Central Atlantic Fishery Commission (WECAFC), etc.) where scientists from member nations meet periodically through seminars,

workshops and working parties. Information is exchanged and joint activities are proposed, often undertaken, and subsequently evaluated. The intensity of these activities varies from region to region. By the nature of their charters and operations, some of these bodies have not as yet been able to reach the appropriate decision-makers with their scientific findings and recommendations related to the exploitation and management of fishery resources.

5.1 Some problems fisheries scientists face in the national decision-making process

In this section some problems that fisheries scientists often face with the decision-makers are presented, with some suggested remedies. These problems do not necessarily represent those found in any one fishery but are a composite drawn from the experience of scientists involved in many pelagic fisheries.

- Scientists are expected to draw conclusions to meet requests for advice within a fixed time schedule. In many instances, information is not available or cannot be processed in time.
- The resource system itself varies with time so that the basic scientific conclusions available today may have to be modified, perhaps radically, at some time in the future. Assessments are usually out-of-date by one to five years, as a result of data and analysis delays.
- These and other factors mean that scientific assessments can never be precise or permanent. So the scientist is always faced with the problem of convincing the reluctant politician or the sceptical fisherman that he really can make assessments which provide a sound basis for action.
- In order to provide quantitative assessments, the scientist must try to give confidence limits to his central figure. These, although scientifically sound, may be quite wide, and therefore may leave the scientist open to the criticism that "he does not know what he is talking about".
- The decision-maker, faced with an unpalatable figure from the scientist, will almost always choose to adopt a figure within those confidence limits that best suits himself. The scientist may anticipate this response by the decision-maker, causing him to modify his presentation.
- Scientists are often placed in a position of confrontation with industrial, political or other objectives. This makes the implementation of a rational scientific advisory function extremely difficult, and scientists must be prepared to defend their conclusions against often irrationally opposing views. The problem is that the scientists can only rely on the amount and quality of the data and knowledge they have available (which depends, in part, on the budget and support provided by other sectors), while others in the sector have more powerful (often more emotional and less scientific) political, economical, and social arguments. As a way of pressing the decision-maker, others in the sector can argue that they want to maintain high yields, profits, employment and so forth, while scientists usually argue that they want to avoid overexploitation and to heighten the probability of preserving the resource.
- Normal processes of scientific debate in a lay forum give the impression of incompetence and/or ignorance. Scientific debate should therefore be conducted in a scientific forum and the question of what can, and what cannot, be concluded should be made clear in presentations to the public.
- Predictive fisheries assessments, like all such ventures, will sometimes be wrong. Inevitably, such errors will be used to undermine confidence in the scientists.
- A particular case of such predictive assessments is that of "risk of collapse" calculations. The scientist will be asked to justify why preventive medicine is necessary on probabilistic evidence only.

- Finally, the scientist finds that the decision-makers to whom he is providing information are often likely to be replaced, usually by someone less familiar with his or his organization's research and assessment activities and all his work (including attempts to gain the confidence of the decision-maker) has to begin again.

5.2 Suggested remedies for dealing with such problems

The fishery assessor must accept, as a fact of life, that he will usually be working in an atmosphere that is either indifferent or hostile to his assessments. It has been aptly said that there is no good time to tell the fishermen to stop; if they are doing well they will not listen and if they are doing badly they cannot.

Nevertheless, the process of "educating" the decision-makers about the scientific basis of management must be pursued continuously in a variety of ways. Only then will it be reasonable to expect the scientist to be listened to and understood when there are sharp declines in fish catches.

Confidence must be established between decision-makers and scientists, so that decision-makers can rely on the scientists to: (1) know what they are talking about; (2) admit honestly what they do not know; (3) be impartial in the sense that they have no particular prejudice for one policy over another; (4) be prepared to put their scientific status and integrity on the line to defend their advice as being the best and most effective that is possible, given the circumstances; and (5) not be afraid to admit when they are wrong.

It is important to stress that no less should be expected by decision-makers from other interest groups (such as industry or conservationists) providing advice and recommendations. Specifically, the decision-maker should be aware of their biases and relative credibility. Scientists and their findings are constantly under peer review while other interested parties and their findings are often able to avoid similar scrutiny.

However tempting it may be to provide "softened" scientific assessments in order to make them more acceptable, that temptation must be regarded with caution. It may rebound sooner or later and the scientist will have forfeited his credibility. However, this is difficult - all too often the best policy is rejected as too extreme, leaving no policy. "Softening" is sometimes necessary to achieve results, but it should be done by working with decision-makers in a constructive manner.

Fishery assessments are highly sophisticated scientific exercises calling on a variety of skills, a penetrating knowledge of the biology of the system, and a good understanding of the fishing operations and the industry. There is everything to be gained by treating them as such, and exposing the conclusions to the thrust and parry of open-scientific peer review. Both the substance of the assessments and the confidence placed in them by decision-makers should thereby be enhanced.

Because the fisheries science community is essentially international, it would be desirable, when possible, to extend the scope of scientific review and criticism to the international level as a regular procedure. This would avoid the need for national decision-makers to feel that they must seek another opinion in the hope of finding another, politically more palatable, option. Related to this point is the increasing role of marine scientists as consultants hired by industry to present their view of, and to emphasise the uncertainty aspect of, resource exploitation.

Scientists need to understand what the needs of the policy-maker are, including what he is doing and why (this is essential for the scientist to know in order to give good advice). The decision-maker also needs to understand the scientific and other advice that he receives about the fishery. International reviewers have a higher probability of objectivity, but may suffer from lack of intimate knowledge of the fishery and its particularities; however, these obstacles should not be difficult to overcome.

5.3 Some sources of problems related to fisheries management

Problems faced by fisheries scientists in the decision-making process result in large part from factors over which they have little control. Some representative factors

for comment are: conflicting time-scales, perceptions about the resource (and its abundance), uncertainties in the physical and societal setting, fishing as a subsector of society, and discounting the past.

5.3.1 Time-scale

The importance of time-scales cannot be underestimated. Pelagic stocks are often eruptive in nature, and accordingly have high potential increase rates over periods of several years. Harvests in excess of the surplus production cannot be sustained for long as the biomass "reserve" is rapidly depleted. Stocks can be reduced to undesirably low levels by overfishing for a period as short as one to two years.

Over the long-term, many pelagic fishes have low production/biomass ratios, but because of their eruptive nature (serial correlation, etc.) and their high variability, they may be highly productive over intermediate time-spans. Time scale is important, but it is the eruptive time-scale that is important to pelagic fisheries. Depletion sets in very rapidly once the eruption is over, and the spawning base should be maintained at a minimal level for eruptions to achieve a useful level. Flexible management procedures are therefore required that can react on a time-scale shorter than one year, should evidence of stock depletion become manifest.

As biologists, climatologists and oceanographers constantly consider the relevance of different time-scales for their research, so, too, must those who seek to understand the societal implications of variable fish catches. For example, different groups discount the value of the future according to their needs and their objectives. Fishermen may find time-scales of days and weeks most important to the attainment of their objectives, while industrialists may think in terms of seasons and years. Policy-makers may respond to long-range development horizons of decades, or to short-term political horizons of years, or to the extremely short-term crises that they may face not only in the fishing sector but in other sectors of society as well (e.g. elections or government changes). Superimposed on all of this are the time-scales of nature which can range from hours to centuries. Often short-term objectives or benefits prevail over longer-term considerations which often become burdensome costs that will have to be borne by future generations of society (as well as by future generations of decision-makers). The actors involved in the fisheries who hold these conflicting objectives and time horizons (e.g. earn enough support from this decision to stay in their position; earn enough money to feed their family this week; earn enough money this season to amortise loans for their equipment; pay for their bills for the boat, nets, etc.; earn enough in the next few years to buy a house; earn enough from the fishery to subsidize economic development goals) must take into account nature's varied time-scales while they deliberate on how to exploit these fish stocks which, for whatever reason, are highly fluctuating.

Members of society, including decision-makers at all levels of social organisation, have tended to perceive pelagic fish resources as abundant and in some cases virtually unlimited. Yet the fact of the matter is that the ability of a fish population to regenerate itself is directly tied to, and dependent upon, the balance that is established between its rate of regeneration, which depends primarily on environmental processes, and its rate of exploitation. Not only are other marine species predators to these fish populations, so too are fishermen and their purse seines. Even the environment (e.g. fluctuations around the mean values of physical variables in the marine environment) may play a role and, in fact, plays a major role in magnifying the effects of predators and other causes that may alter the ability of the fish population to regenerate itself. This suggests that pelagic fish populations must be perceived as only conditionally renewable and, hence, managed more rationally.

5.3.2 Perceptions of abundance

Fishermen and the fishing industry base their appraisals of the abundance of a resource on the index to which they are sensitive, i.e. catch rate (or CPUE). This means, however, that they may fail to appreciate the fact that (a) in a situation where catchability (proportional vulnerability) is inversely related to total biomass, catch rates may be maintained despite a decrease in abundance; and (b) where selectivity changes with age, CPUE trends may lag behind those of total biomass, so that catch rates fall only some

time after a general decrease in total biomass. Furthermore, even if the fishing industry should become aware of a drop in catch rate, it may be disinclined to acknowledge it, knowing that this will cause disruptions in fishing activities. Price may increase as catch rate drops, helping to offset the economic perception of a declining resource by the fishermen.

In cases where a fishery starts exploiting a resource when at a biomass level which is a reasonably high proportion of an average "carrying capacity", the initial catches will comprise not only the production capabilities of the resource, but also a component (possibly the major component) arising from cropping down the initial biomass. This is a once-only benefit, but contributes to misguided perceptions among entrepreneurs of long-term yield potential, leading to "over-shoot" of expectation, hence overinvestment and overfishing.

5.3.3 Managing under uncertainty

One of the major problems that policy-makers have to address is uncertainty; uncertainty in the physical environment, uncertainty surrounding the fish resources, and uncertainty in the scientific information as well as uncertainty in the economic, social and political systems. In the biological sciences the uncertainties in the physical environment are exposed and discussed by scientists, yet such uncertainties create great pressures for decision-makers. As there are competing interests in society, uncertainty in the scientific information allows enough doubts about what the "real" situation is, that the policy-maker is often at liberty to discount this input (especially if opposing scientific arguments cancel each other) and to make decisions to reduce some of the uncertainty in his broader political and economic environments.

Crises in society require immediate attention of decision-makers. Uncertainty in the biological and environmental information he is given allows him to "take a chance" to achieve a more immediate goal at the risk of some catastrophe that might (or might not) occur at some unknown time in the future. By the time his decision has proved to be erroneous he will probably no longer be accountable as most likely he will have moved to another decision-making position or, perhaps, even to a similar position in another sector of society. Thus, policy-makers can use uncertainty to their political advantage when they perceive that there is a need to do so, because they will not be held accountable: "success has many fathers but failure is an orphan".

5.3.4 Fishing as a sub-sector of larger systems

In developing countries fishing is considered either for food production, or as an item in the natural resource extraction sector. What premium is placed on either of these categories determines the relevance of predominance of the fishing sector. If the fishery is mainly considered as a food item, the state of food supply and the need for protein for national health becomes important. The availability of protein from other sources also determines what importance should be given to fish as a prime or cheap source that should demand attention.

If the fishery is viewed as an important factor in the extraction sector, its role as a revenue earner in foreign currency or in raising the per capita income becomes relevant. If it happens to be a prime earner of foreign exchange, such as anchoveta and now sardine in Peru and Chile, then its importance in the larger system is raised higher; however, fishing is not only an economic activity but also a political, cultural and social one. Therefore, to understand how a particular fishery is, and should be, managed requires investigations by social as well as physical scientists (Glantz, 1983).

5.3.5 Discounting the past

There now exists an expanding set of case histories of sharp declines in neritic pelagic catches in different regions of the world, at different times, the causes of which have not been agreed upon (generally speaking): South African and Namibian pilchard, Peruvian and Chilean anchoveta, Hokkaido-Sakhalin herring, California Pacific sardine, and so on. The societal dislocations that have resulted from such declines have been recorded, although not in forms conducive to comparative analysis. As socio-politico-economic systems differ so, too, do the implications for society of the decline in fish

landings. If a country's fishing sector has been heavily dependent on one main fish population (e.g. Peru in the 1960's), the social dislocations would be greater than in a country that exploits a multispecies fishery. It is time to assemble these case histories and to move such experiences from the realm of anecdotes into the realm of comparative analysis of the impact of declines in fish landings. One of the most important ways of preparing for the future is to understand the past. Scientists and policy-makers must ask themselves when will they have had enough information about the implications for society of sharp declines in fish catches.

6. RECOMMENDATIONS

(a) Because of the significant social and economic consequences that can result from the highly fluctuating catches of many pelagic neritic resources, decision-makers must be made aware of the growing number of examples of severe dislocations that have resulted from the heedless exploitation of such fisheries.

(b) An assessment should be undertaken to compare the effects of a stoppage of fishing activity resulting from a management decision taken at the first indication of a decline in biological productivity with the effects of a stoppage of such activity at some time in the future because of a sharp reduction of the fish population.

(c) In managing neritic resources, decision-makers must give more consideration to the long-term interests of society than to the short-term political and economic interests that tend to dominate a policy-making process.

(d) The formal decision-making process should incorporate an advisory group that should encompass a wide spectrum of interest groups (of which scientists would be one), ranging across a continuum from conservation to exploitation. This advisory group should not be a replacement for a scientific advisory group, whose role should be strengthened relative to what it has been in the past.

(e) Economic measures should be used to discourage additional growth in the fishery before the declining state of the resource dictates such discouragement. Banking institutions and development financing programmes must be informed and coordinated with management. Consideration should also be given to implementing economic measures in order to, for example, sustain the sector through periods of poor catches, buy-back vessels for effort-reduction, and encourage diversification. (This should be done during the early growth stage.)

(f) Scientific appraisals must be discussed as widely as possible, especially among the competent scientific community, both national and international. The results of such appraisals should be published in a timely manner. Independence (impartiality) of the scientific appraisal is essential. The scientist must not be pressured by his national political decision-maker to provide "rosy" projections when available scientific information suggests otherwise.

(g) Scientists should be given opportunities to present their findings in person, to respond to questions and criticism and to stand by or modify their conclusions. To do otherwise would be a potential source of misunderstanding and lack of confidence.

(h) An effective, reliable communication channel should be established among scientists, fisheries managers, and policy-makers so that a proper understanding and atmosphere of mutual trust can be developed, one that will become institutionalised and not dependent on the temperament of the individuals involved at a given time.

(i) Stock-dynamic models provide estimates of the most appropriate current yield, taking into account only biological factors. However, it is clear that other social, political, and economic considerations play an important part in the final management decisions that are taken. It should be required that each of these considerations and their alternatives be investigated and addressed as thoroughly as are the biological considerations. These factors must be identified and assessed in order to understand how fisheries are managed.

(j) A management scheme should be established in which fisheries scientists would work on an interactive basis with social scientists, including economists, in order to more effectively assist decision-makers in their role as societal guardians of living marine resources, especially given the large degree of uncertainty that surrounds the existence and exploitation of these resources.

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P A R T V

REPORT OF THE WORKING GROUP ON FISHERIES MANAGEMENT,
IMPLICATIONS AND INTERACTIONS

by

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ABSTRACT

Variability is an inherent characteristic of neritic fisheries. This is usually associated with both heavy fishing and changes in environmental conditions. Consideration needs to be given to the biological, physical and human components of the management system. This includes controlling the type, size and amount of fish harvested; trying to respond in a timely manner to events in the fishery imposed by climatic processes; and taking into account economical, social and political considerations. Main users of the resources, their objectives and potential for conflict are identified. Management should be prescriptive and preventive rather than reactive. Three broad-scale fishery strategies to exploit variable resources are suggested: a fluctuating fishery, an opportunistic or migrating fishery, and a diversified fishery. Fishery activities should be regulated to tighten protection at low levels of abundance and allow fishing to expand when fish abundance increases in order to maximise gains in periods of great abundance and minimise losses during periods of low abundance.

1. INTRODUCTION

The general topic of this Expert Consultation was the variability of neritic fish populations. The specific goal was to analyse this variability, particularly when it takes the form of rather rapid, large-scale changes in total abundance, species composition and general distribution, and then to consider the effects that these changes have on fisheries and the various sectors dependent on fishing.

The reports of three other working groups deal with the variability of both the resources and the environment, how these should be studied and monitored, and the societal and economical implications of this variability. This report presents the results and conclusions reached by the Working Group on Fisheries Management, Implications and Interactions and starts with a review of the major components of the management system, and of the main users of the fish resources and their objectives. The report concludes with a brief discussion of several alternatives that might be applicable in the management of highly variable neritic fisheries.

Valuable technical inputs and substantial sections of this document were produced by J. Magnuson and R. Serra, who acted as rapporteurs, and by other members of the group. These included H. Belvêze, R. Beverton, J. Bravo de Laguna, B. Brown, R. Crawford, P. Fréon, S. Garcia, R. Jordán, E. Kwei, J. Lleonart, Loh-Lee Low, A. MacCall, M. Murillo, P. Shelton, S. Tanaka, H. Vilhjalmsson and Y. Znamensky.

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1.1 Highly variable resources

From the management point of view a highly variable resource can be defined as one for which the level of biomass or production cannot be controlled with sufficient precision by only regulating the amount of fishing. When fish resources show wide natural fluctuations, the "equilibrium" concept used for more stable resources becomes unusable in the shorter time scales relevant for management; nevertheless the needs for management are greater and more demanding because of the high economic and societal costs involved in the fluctuations and collapse of large neritic fisheries.

Several of the reviews presented at this Consultation (see Proceedings, Vols. 2 and 3) reinforce the views that fluctuation and eventual collapse of neritic fisheries are usually associated with a combination of both heavy fishing and changes in environmental conditions. These two causal factors should therefore always be kept in mind whenever dealing with fluctuating neritic fisheries.

Variability in recruitment is recognised as the major immediate cause of fluctuations in neritic pelagic resources, although changes in behaviour and in biological characteristics of fish populations, such as the natural mortality and growth rate of post-recruitment stages, have also played an important part.

The effect of the environment on the fluctuation of living marine resources is recognised, and it is recommended that more attention be given to this source of uncertainty. Recruitment variability in many important neritic fish populations appears to be closely linked to changes in environmental conditions. In fact, recruitment variability due to environmental factors may be even greater than the variability due to changes in abundance of the parent stock size (e.g. Csirke, 1980; Garcia, 1983). Parrish *et al.* (1983) have made a review of some important environmental processes that might have a major effect on recruitment variability in eastern boundary current systems, and there is a good deal of evidence suggesting that most of the recruitment variability is determined in the very early life history stages of the fish (e.g. Sharp, 1981). However, little is as yet known about the specific mechanisms determining the close relationship between the environment and fluctuations of neritic fish resources which so greatly affects fisheries around the world.

It is also recognised that fishing has played a major part in exaggerating resource fluctuations and precipitating the collapse of a number of neritic fisheries, particularly pelagic ones. In fact, we are probably over-emphasising the role of nature on the variability and eventual collapse of pelagic neritic fish populations by focussing on those fisheries that have collapsed in the last few decades. There are various examples of pelagic fisheries which have been maintained for periods of up to fifty years or more without signs of collapse, but fishing has become very intensive and efficient in the last few decades. This has helped to intensify natural fluctuations in fish populations and, at the same time, has made fishing communities much more dependent on the productivity of fish resources, thus becoming more sensitive to their fluctuations.

Some neritic fish resources are characterised by the existence of large pulses or oscillations in their abundance. For these resources, traditional biological and economic models that assume steady state conditions might still be useful in the long term, but are often invalidated in the short term. During periods of increased abundance, yields obtained from the exploitation of these resources can reach very high levels, and rapidly become major items in a national economy. Thus, there is a greater chance that unexpected and large changes in abundance will have drastic societal and economical effects on markets, employment, revenues, foreign exchange, etc. Also, the chances of developing into an over-exploited situation are greater with highly variable resources, since once the fisheries have developed to a certain level (usually following an increase in abundance period), all efforts will usually be made to maintain those high levels even if the resource enters into a period of reduced abundance as part of its natural evolution.

1.2 Objectives of fishery management

The general objectives of fishery management are to provide wholesome food, gainful employment and economic benefits. In managing its fisheries, each nation will necessarily have to balance the maximisation of these benefits in the short term against the long term benefits that come from more stable catches, more stable employment and more stable economic gains, as well as ensuring preservation of the resource for future options, of both the nation and mankind.

Attainment of these objectives also includes minimising conflicts among the several sectors involved. Effective management should rationalise attainment of these objectives using scientific information on the resources, their environment, and socio-economic considerations. When managing highly variable resources another objective is not to aggravate resource fluctuations, and to conduct the development of the fishery in such a way as to maximise gains in periods of great abundance and minimise losses during periods of lowest abundance.

Management should also bear in mind that even if preservation of the resource is not its main objective, it is still an indispensable condition for any other long-term objective to be attained.

2. COMPONENTS OF MANAGEMENT SYSTEMS

Fisheries management must deal with three primary components: 1) physical component - climate and structure (physics, chemistry and dynamics) of the sea which cause variations in biological productivity and conditions for fishing; 2) biological component - fish populations, their intricate dynamics and interactions with other biota; and 3) human component - social, economic and institutional atmosphere in which management functions.

So far, fisheries management has tended to focus on the biological component, i.e. the individual population being fished. Based on the type, estimated state, and apparent dynamics of each population, management actions are implemented which supposedly maintain or alter its state. By focussing on the biological component, the manager or decision-maker is limited to a number of actions or tools to bring about the necessary balance between the biological and human components, while taking into account the physical components that affect both fish and man.

The purpose of this classification into causal manageable components is to illustrate that direct and indirect considerations need to be given to all components, and that, in fact, more management alternatives are available than just the customary methods designed to control fish catch and fishing effort.

2.1 Physical component

Weather and climatic events initiate large changes in fishery populations. Such events include El Niño types of phenomenon, changes in ocean current systems, the dynamics of sea ice, and long-term climatic changes that cause gradual warming or cooling of the seas. Effects of these large-scale climatic events are well-illustrated through the histories of the Peruvian anchoveta fishery and the Japanese and Californian sardines. Many other fisheries have also been greatly affected through smaller-scale climatic variations.

This Expert Consultation calls attention to the great effects that these environmental events have on fish populations, hence fisheries and supporting sectors, and the necessity for managers to pay more attention to them in planning and decision-making. Climate cannot, of course, be managed, but rather the opportunity is to respond in a timely manner to events in the fishery imposed by climatic processes.

Fishing (as well as marketing, research, etc.) strategies may be altered as predictable climatic events occur. Contingency plans should be ready in case of catastrophic climatic events. Such management actions would be designed to control the human components of the management system, hence the related biological responses. For example, a manager may wish to catch as much of a resource as possible (and accumulate gains for later) before a predictable climatic event causes catastrophic mortalities in the fish population; or may choose to mitigate nature's damage by lowering catches, starting to displace excess labour to other sectors, and by promoting alternative uses of equipment and gear before the predictable climatic event actually occurs.

There are not many practical ways to manipulate the sea to serve fisheries' objectives; however, man's actions can cause localised changes in the physical and chemical characteristics of the sea and thereby affect fisheries' production. Some of these possibilities are:

- a) use of physical structures to create fish refuges or concentrate fish for harvesting. These can be artificial reefs or floating structures to attract fish. Use of high intensity light as aggregating devices during fishing at night is also common. Conversely, if artificial structures serve to concentrate fish, thereby increasing fishing mortality to undesirably high levels, the management option to remove them should be considered;
- b) introduction and control of nutrients or contaminants into the sea,
- c) introduction and control of warmer water from power-generating plants into the sea; and
- d) control of the volume of fresh water entering estuaries through the building of dams.

These are but a few obvious examples showing how man's actions or management actions may affect the physical component and, therefore, affect production and catch. Most of these effects may be localised, but for estuarine or artisanal fisheries, their impacts on specific resources may be great. Such factors should be considered as decisions are made. As technology and human populations increase it becomes even more important to consider man's actions that affect the physical and chemical contents of the sea which affect fisheries' production.

2.2 Biological component

This includes both the specific resource population being fished, and other biotic elements of the ecosystem. Management methods have concentrated on controlling type, size and amount of fish harvested in order to maintain continued production of each resource. These are the primary ways in which managers have intervened in the fishery management system. Following classical methods, the manager has at his disposal the following options:

- a) Catch quota - by species, area and time period combinations. Catch quotas are usually designed to achieve some goals based on the biological productivity of the stocks. The productivity is measured usually in terms of sustainable yield, whether at maximum or intermediate levels.
- b) Fishing effort. Fishing effort may be controlled through various means, including manipulations of the type of gear, amount of gear (hours trawling, length of gillnets, etc.) number of vessels, number of fishermen, duration of fishing season, entry of new fishermen. The regulation of fishing effort is usually designated by species, area, and time.
- c) Biological characteristics of fish caught. The most important characteristics that have been considered in management decisions have been minimum size or age at first capture, sex of fish to be harvested, and phase of life cycle for exploitation. These characteristics determine the impact of fish size regulations, type of gear and mesh size for example.
- d) Time and area restrictions - to provide refuges for spawning, nursery, feeding or growing activities. Alternatively, fishing seasons may be opened to harvest fish for their roe content, or take advantage of locally high abundances or seasonal changes in fish condition (e.g. fat content).

Management of neritic systems has generally been through single species models; however, the impact of fishing is often associated not only with alterations in abundance of exploited species, but also with changes in abundance, distribution, or population dynamics of unexploited species or food items; these changes lead to alterations in trophic pathways. Such changes may be most noticeable in secondary consumers such as predatory fish, birds and mammals, but may also be apparent in terms of plankton abundance or composition, detritus and nutrient levels, nutrient recycling rates or changes in the extent of anoxic layers.

While few, if any, neritic systems are sufficiently well understood to allow management or prediction through ecosystem models, such models can still play a useful role in structuring information on linkages and transfer rates within a system. Such a model can be used to help answer such questions as "What would happen if predators were removed?" The exercise of ecosystem model building can thus play a useful role when management is aimed at maintaining ecosystem integrity rather than just the stability of yield from a single population.

An example of the interaction between environment, a prey species, their predators and competitors, and man, is provided by the Peruvian system. Core studies of sediments have shown that anchovy has been the dominant species in the system for millennia (De Vries and Pearcy, 1982). Also there used to be a close link between the Peruvian anchovy and the populations of guano birds off Peru (Murphy, 1981). The collapse of the Peruvian anchovy in 1972, which coincided with a major El Niño event, and a ten-year period of intensive fishing pressure, altered the species dominance in the system for apparently the first time in thousands of years. Abundance of sardine, jack mackerel and mackerel increased dramatically while anchovy was depleted. The overall abundance and relative proportion of the three main guano birds, cormorants, boobies and pelicans, also changed (Tovar, 1983). Fishing in this instance appeared to have perturbed the fish-seabird-El Niño interaction to such an extent that the species dominance was drastically altered. Such system changes are not amenable to analysis by single species models.

2.3 Human component

This includes the institutions responsible for management, the users of the resource, and all other relevant social, economic, and political considerations.

Governments represent the people and have the responsibility to look after their interests, and are therefore the vested custodians of the fishery resources. The government sets fishery objectives, gathers and disseminates information, develops management plans, appoints authorities to make fishery decisions, allocates the resources among users, and negotiates with other nations on the use of shared resources or interests.

In fisheries' management, it is really human activities that can be, are, and should be carefully regulated. Man's fishing activity is an imposed mortality on fish populations and therefore implies a perturbation of the marine ecosystem; it also implies social and economic changes in the human community. These activities must be monitored and regulated to achieve continued and prudent use of biological resources, while providing satisfaction, order and harmony in the human component.

Most of the options the manager has with which to achieve the goals of fisheries' management are in the human component. These goals encompass social, economic, and political considerations. Actions involve the creation of the proper social, economic and political atmosphere to effectively and reasonably harvest the fishery resources. The atmosphere may have to be altered depending upon the goals of management, state of the resources, and status of the fishing industry. In this arena the skill of the manager is truly tested.

There is also an international perspective to the human components. Fish populations may be transboundary or shared between nations, foreign nations may be granted access to a nationally-managed resource, markets may be international, etc. Often, a national fishery has different objectives from other countries interested in, or sharing, a resource. This makes intergovernmental negotiations necessary in order to successfully manage such resources, and the manager may then be faced with a new set of values to consider, on top of the national ones he already has.

According to the new Law of the Sea, coastal states have sovereign rights over living resources in their Exclusive Economic Zones (EEZ) but, at the same time, foreign nations could be given access to surplus production. Effective access arrangements could be made through bilateral governmental agreements, joint commercial ventures, and cooperation through national and international organizations.

International organizations could also play a useful and important role in the regulation of shared, as well as transboundary, stocks. Coastal states with a shared stock in their zones could use an international organization of which they are members for the elaboration of regional fishery plans and regulations. Conversely, a coastal state could use such international forums to obtain outside views for developing its own management plans.

When the same fish population is located inside and outside the EEZs, key roles may be played by regional fishery organizations. Such organizations could be established with representation both from coastal states and states whose fishing fleets are operating in or planning on operating in the area. To assist in management, a common data system and cooperative research would be useful.

3. RESOURCE USERS AND THEIR OBJECTIVES

Fishery utilisation affects all citizens of a nation either directly or indirectly. Catching, processing and marketing fish is a way of life for some of these citizens, making them the direct users of these fishery resources. Other sectors of the society are indirectly affected, but the impacts can be major.

3.1 Direct users

Direct users can be grouped into the following categories: a) fishing sector, b) industrial sector, c) marketing sector, d) sport fishing, and e) consumers. These are not mutually exclusive categories because an individual, or organization, could participate in several uses simultaneously.

3.1.1 Fishing sector

The fishing sector is in direct contact with the resource. It is, in turn, made up of a series of groups of individuals (or subsectors) whose objectives do not necessarily coincide and who are affected in different ways by the success or failure of the harvest. We can distinguish three subsectors: small-scale fishermen, ship owners, and crews.

Small-scale fishermen are the traditional users of the resource. They usually own their means of production and depend on the resource and how available it is to maintain their traditional standard of living. They derive, proportionately, the least benefit from peak fishing abundances, because their boats and gear are adapted to typical fishing conditions and their haul, transport and marketing capacities are limited. When there are few or no fish they are deeply affected both by their low-technology approach to the problem and by the fact that their traditional source of income could vanish. At the same time, they are a flexible group that can switch, at low cost, to fish other species or to other artisanal occupations. Their basic objective is to maintain an adequate catch level so that they can go on fishing for as long as possible. This group may or may not have an economical importance with regard to influencing the management process, but undoubtedly it is of major social significance.

Ship-owners own the capital represented by the fishing vessels. They may or may not have come from the fishing sector. Their major objective is to maximise net benefits from their investments. They are less closely bound to the fisheries sector than are the small-scale fishermen because they are actually investors who have put their money where they hope to obtain profits. This sector therefore puts pressure on their crews to boost the yields of each vessel, and on management to avoid management measures which it perceives as reducing profits. Its strategic position within the network of sectors involved in fishing means that besides representing an important economic sector it has some control over the people doing the fishing while, at the same time, it is close to the centres of decision-making. It can play a major role in influencing state fishery policies and management strategies.

The situation of the crew is very similar to that of the small-scale fishermen. The difference is that they earn wages or shares. Here we can distinguish two groups of people with different objectives: skippers and crews. The skippers, as representatives of the ship-owners, are responsible for operating the boats at sea. Their objective, therefore, is to get the most out of both vessels and crews. In the short run they stand to gain a great deal, but should the catch decline or not bring in as much as expected, they are the first to suffer the consequences. This is aggravated by the fact that they are too specialised to fit in anywhere else in society at a comparable income level. In an indirect way, skippers have an impact on management in that they are the ones who influence the ship-owners to exert pressure on management. The basic objective of the crew is to ensure that they will have a job and earn adequate wages, and as with the small-scale fishermen their influence on the management process is based on social rather than economical considerations.

3.1.2 Industrial sector

The fishing industry, as processor, either artisanal or industrial, of the product harvested by the fishing sector, is the second major user of the resource. In this sector, there are also two kinds of people: industry managers or owners, and workers. The industrialist's basic objective is identical to the ship-owner's, to maximise net benefits from investments. Nevertheless, there are differences in their sphere of action. They are not in direct contact with the resource and their major opportunity to exert pressure on management is in terms of the size of their investment and the numbers of workers they employ. Under normal circumstances, their greatest problem is marketing the product. Unless they have direct interests in the fishing sector, they do not interfere in any major way in management measures, unless the product delivered to them is unsuitable for their markets. The major concern of workers in the industrial sector is comparable to that of the crew in the fishing sector; their objectives are stable employment at acceptable wages.

3.1.3 Marketing sector

The marketing sector is the third basic pillar of this structure. It plays the role of distributing and promoting the product and its basic objective is to maximise profits from this activity. It differs from the preceding two sectors in that its capital investment is relatively small in proportion to its profit, and in that it has a limited capacity to exert direct pressure on the decision-making process. When catches decline, the marketing sector adapts very easily to the new situation by reducing its activities and therefore its overheads.

3.1.4 Sport fishing

Sport fishermen are direct users. They use the resource for recreation and generate socially and economically important side industries, such as tourism. In some cases, recreational fishermen, owing to their large numbers and social position, can exert a strong influence on management.

3.1.5 Consumers

Consumers constitute the group of direct users of the resource with the most passive role within the management system, despite the fact that they are the ultimate element of the fisheries system. A distinction should be made, however, between national and international consumers, although they have in common the basic objective of obtaining fishery products at the lowest possible prices.

International consumers, as a source of foreign currency, may have a major impact on the development and success of fisheries although, in general, their influence on how fisheries are managed is limited and is mainly exerted through the marketing sector. International consumers can more easily switch to alternative products and/or suppliers, and therefore are much less affected if a fishery collapses.

National consumers are the major users of the resource. Most of a country's population can be considered as belonging to this users' category. Their basic objective is to obtain fishery products at the lowest prices but they are also expected to benefit, at least indirectly, from the exploitation of the national resources carried out by other users. As citizens, they are the owners of the resource. Through their taxes they help to generate the capital for the investments of the other users. If the fishery and the industry collapse they, through taxation, bear the brunt of the consequences. Their capacity to exert pressure on management is low and is manifested through social communications. If and when a fishery fails the national consumer tends to be the ultimate loser.

3.2 Indirect users

Among indirect users of the resource we can distinguish: a) support industries, related to the fleet and fishing industry, and b) enterprises associated with port buildings and related infrastructures.

3.2.1 Support industries

The main group of indirect users is the support industries. They are not only responsible for building the boats and factories, but also provide the means of catching, canning and shipping the catches. They can play an influential role in a country's fishery policies by, for example, exerting pressure to maintain ship construction even at times when the state of the resources would advise a cutback in fishing effort.

In general, support industries all work to make their investments profitable. Their specific objectives vary in accordance with their specific relationship to the resource and their degree of dependence on its fluctuations. The people who make boats, nets and other special gear are completely dependent on the fishing sector; thus they are very dependent on successes or failures of the fishery and therefore have similar objectives as the fishing sector. Their capacity to exert pressure varies with the size of their labour force and the extent to which their companies participate in the national industry. The clearest examples of such users are the shipbuilders, and shiphandlers. Other support industries are less dependent on the fishing sector. Manufacturers of various kinds of containers, and food suppliers, are in a position to offer their goods and services to other sectors of society.

3.2.2 Port and infrastructure building

Important indirect users are the builders of fishing-ports and related infrastructures. Their participation in the benefits produced by a major fishery resource occurs at an early stage in the development of a fishery and their objectives have usually already been attained by the time the crisis takes place. During these early stages, they can be very influential in determining policy on port location, size, and so forth. Their influence virtually halts once the port infrastructure has been completed.

Table 1. Relation and potential for conflicts between users of fishery resources

	State	Ship owners	Industrial capital investors	Infrastructure enterprises	Marketing	Crews	Artisanal fishery	Support industry	Industrial employees	Consumer	Sport fishery
State	0	-	-	-	+	-	-	-	-	+	0
Ship owners	-	+	+	0	+	+	+	-	0	0	-
Industrial capital investors	-	+	+	0	+	0	+	-	+	0	0
Infrastructure enterprises	-	0	0	0	0	0	0	0	0	0	0
Marketing	+	+	+	0	+	0	+	0	0	+	0
Crews	-	+	0	0	0	0	+	0	0	0	+
Artisanal fishery	-	+	+	0	+	+	-	-	0	-	+
Support industry	-	-	-	0	0	0	-	+	0	0	0
Industrial employees	-	0	+	+	0	0	0	0	0	0	0
Consumer	+	0	0	0	+	0	-	0	0	0	0
Sport fishery	0	-	0	0	0	+	+	0	0	0	0

3.3 Conflicts among users

Different users interact with each other and the linkages and interdependences among users can be, under certain circumstances, important sources of conflict which at the end are major sources of concern for fisheries management. Major conflicts may be observed within a user group owing to competition to catch, sell or buy fish or fishery products. There are also potential sources of conflict between different users.

Table 1 summarises the relationship between users and gives some idea of the existing potential for conflicts between and within groups. High potential for conflicts between or within groups is indicated by (+), low potential for conflicts by (-), and (0) where, in general, there is no apparent conflict.

It seems that the sector with the highest potential for conflict is the artisanal sector, followed by the ship-owners, the industrial investors and market sector. This high potential for conflict results both from their position within the system and the number of interrelations with other sectors and competitors. In general, causes of conflict tend to grow as the fishery develops, and reaches a maximum whenever major cut-backs in net yield occur.

4. MANAGEMENT STRATEGIES

4.1 Fluctuation patterns

The most common types of variations observed in neritic fisheries can be classified into: rapid unidirectional changes in state, pulses, periodical oscillations, and short-term irregular oscillations.

Rapid unidirectional changes from an observed level of high or low abundance, or catch level, to a new low or high level may occur over periods of 5 to 10 years. Examples of rapid unidirectional changes from a high to a low level of fish abundance (and/or catches) are provided by the Eastern Pacific bonito fishery in the S.E. Pacific (Fig. 1) as well as by some well-known pelagic fisheries that have collapsed in recent years, such as the South African pilchard (years 1960-70), North Sea herring (years 1965-75) and Peruvian anchovy in the early 1970's. The Chilean-Peru sardine fishery (Fig. 2) provides a good example of a rapid and, so far, unidirectional change from a state of low abundance to a state of high abundance.

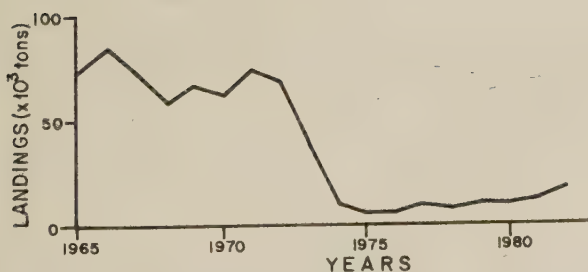


Fig. 1. Annual landings of Pacific bonito (*Sarda chiliensis*) in Chile and Peru (data from FAO Yearbooks of Fishery Statistics)

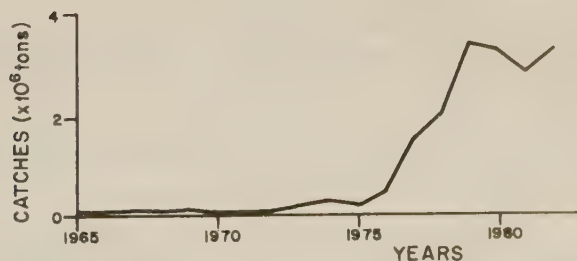


Fig. 2. Nominal catches of sardine (*Sardinops sagax*) in the southeast Pacific (data from FAO Yearbooks of Fishery Statistics)

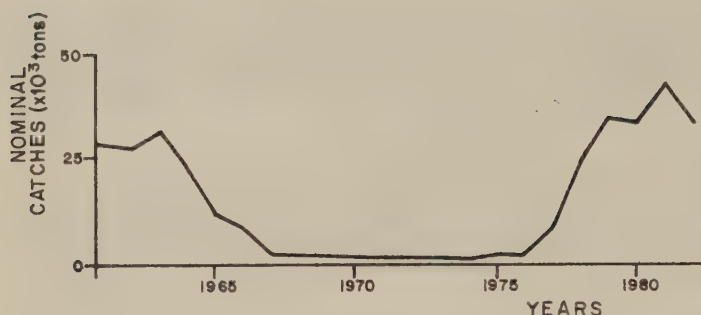


Fig. 3. Nominal catches of mackerel (*Scomber japonicus*) in the eastern central Pacific (data from FAO Yearbooks of Fishery Statistics)

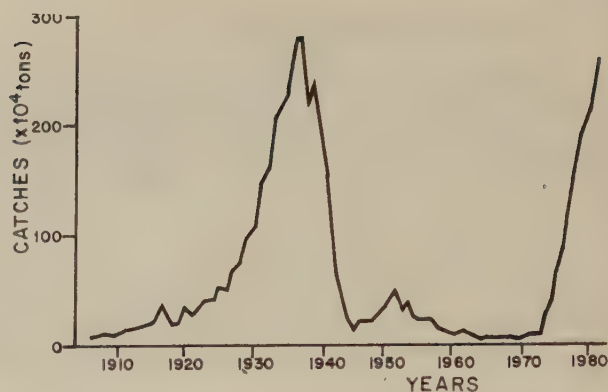


Fig. 4. Nominal catches of Japanese sardine (*Sardinops melanosticta*) in the northwest Pacific (adapted from Kondo, 1980)

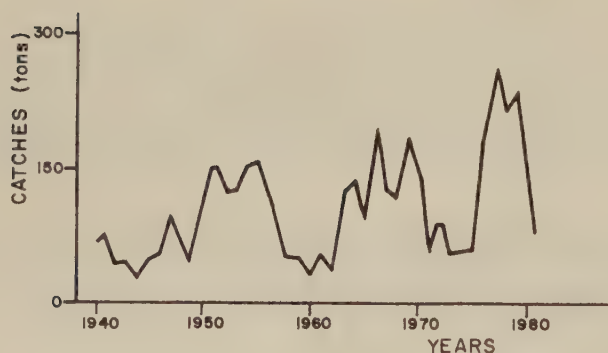


Fig. 5. Nominal catches of hake (*Merluccius merluccius*) off the Balearic Islands (adapted from Oliver, 1983 and Caddy and Gulland, 1983)



Fig. 6. Annual landings of *Sardinella aurita* in Ghana and Ivory Coast (data from Binet, 1982)

Pulses, with a sequence of low or high catches (lasting from 5 to 30 years) are also common in neritic fisheries. For instance, the mackerel fishery off California and Mexico (Fig. 3) seems to have gone through one of these pulses of low abundance in the late 1960's and early 1970's. The Japanese sardine fishery went through a pulse of high catches from 1925 to 1945 (Fig. 4) and a new pulse (or change of state?) of high catches is taking place after a 30-year period of low catches.

Regularly repeated oscillations (e.g. with an 11-12.4 year periodicity related to sunspot cycle) have also been reported in a number of neritic fisheries. Examples are the Balearic hake (Fig. 5) and the alosa in the Black Sea (Ivanov, 1984).

Short-term irregular oscillations, as observed in the Ghana sardinella (Fig. 6) are also common in neritic fisheries.

These patterns of fluctuation are not always clearly distinguishable in a fluctuating fishery. Two or more types of fluctuation may be combined, thus producing a more complex pattern. For instance, Fig. 6a in Butterworth (1983) and Fig. 40 in Zuta, Tsukayama and Villanueva (1983) suggest that both the South African pilchard and the Peruvian anchovy went through a pulse of high abundance (and catches) shortly before their collapse and rapid change of state to a much lower, depleted situation started.

Different types of fluctuations can be considered as particular aspects of the same general pattern in different time scales. Also the phenomenon may appear as a more or less persistent change in state, a pulse, or a regular oscillation depending on the duration of the data series available, and the time scales used in setting management goals and objectives. Moreover, fishing effort may distort or modify the direction and intensity of the changes, and may also modify the fluctuation patterns.

Perception of the type of fluctuation pattern expected and its most likely duration can seriously affect management strategy and can even alter management objectives. As environment-induced fluctuations cannot be controlled, the alternative is to adapt to these fluctuations and thus take as much advantage as possible from periods of high abundance or, consequently, reduce possible losses during periods of low abundance.

For instance, a more or less stable fishery can go through a rapid and unexpected increase in fish abundance and catch rates. If this change is perceived as a short-term pulse, the normal reaction would be to try to benefit from the higher abundance but without making any long-term commitments. However, if the change is perceived as a rapid, but long lasting change in state, this will probably encourage concession of loans, programmes for building new vessels and port facilities, attraction of new fishermen, and so on. Should the prognosis about the fluctuation pattern prove to be wrong, in the first case the fishery would lose some of the initial benefits as a result of delaying its growth in order to fully exploit the new resource, but long-term benefits would not be seriously affected. In the second case, a short-term period of high gains would be followed by long-term losses, social and economical unrest and even collapse of the fishery.

4.2 Phases in the development of a fishery

The usual evolution of a fishery with time can be described by the following phases: (1) predevelopment, (2) growth, (3) full exploitation, (4) over-exploitation, eventually (5) collapse, and hopefully (6) recovery.

Two types of histories, typical of some neritic fisheries are diagrammed in Figs. 7a and 7b, with very fast increase to excessively high levels of fishing effort in Fig. 7a and moderate increase, also reaching high levels but at a slower pace, in Fig. 7b.

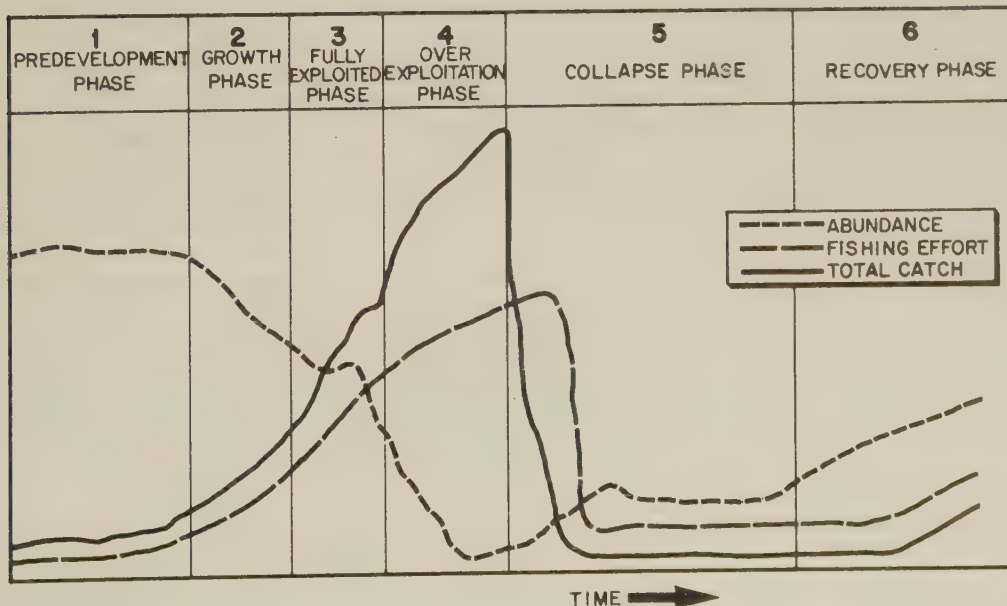


Fig. 7 (a). Generalised history of the uncontrolled development of a fishery

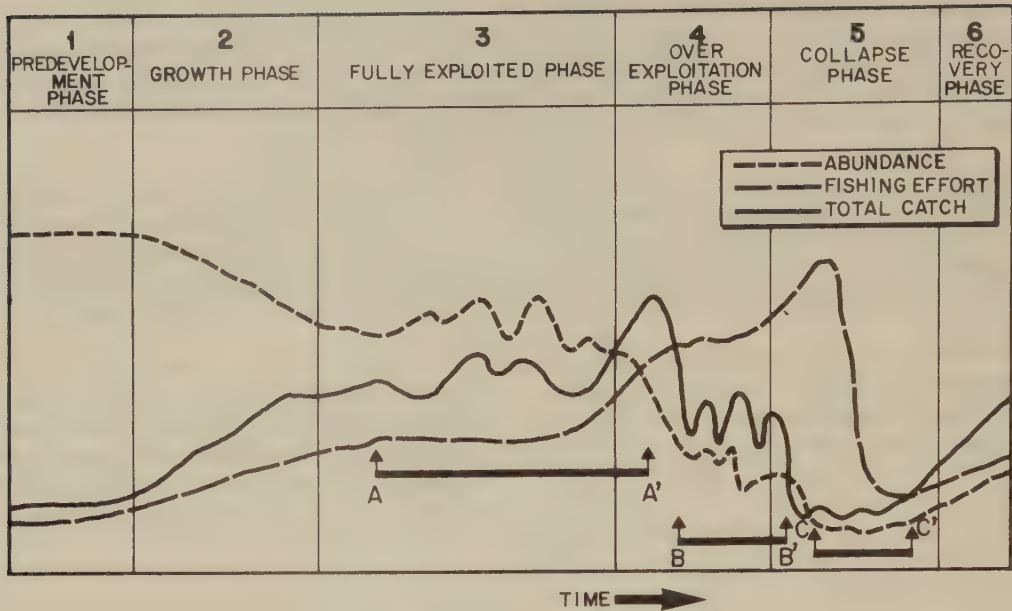


Fig. 7 (b). Generalised history of a developed fishery that tends to fluctuate due to environmental conditions

The first case illustrates the typical overshooting of fishing effort, where the passage from the growth phase to fully exploited and over-fishing occurs very rapidly and, if not controlled, in time leads to collapse. After a period of high abundance, the increased fishing mortality pushes the resource into a declining phase. Catch rates tend to drop but faster increase in fishing effort allows for total catches to increase well beyond the level corresponding to a theoretically maximum sustainable yield. This is usually followed by a severe drop in total yields and even collapse of the fishery.

In the second case (Fig. 7b), effort is lower and catches tend to be sustained at a level of full exploitation over a longer period with no apparent risk of collapse, unless adverse environmental conditions occur. Environmental perturbations may reduce recruitment, cause a reduced abundance of available fish and an increased variability in total catches. The fishery thus enters periods of instability which are illustrated as a series of lines A-A', B-B' and C-C'. Following the first major abundance decline (to the level of period A-A') fishing effort tends to be increased (rather than decreased) to compensate for less abundant and more variable catches and, as in the previous case, effort overshooting occurs, thus reducing the abundance further as well as the catches of fish. As a first major drop in catches (to the level of period B-B') occurs, effort is sustained or even increased (rather than decreased) and this causes the fishery to collapse to an even lower level (to period C-C') where fishing activities just cannot be sustained and there is no alternative other than drastically reducing fishing effort and all related activities. The recovery phase can start at any level but the lower it starts the longer it takes.

The management techniques and objectives vary in different phases of the fishery and are described in the following section.

It is important to note, however, that any large-scale change in an exploited resource will usually initiate an equivalent fisheries response. If the fish stock increases, so will catch rates, total catches and fishing effort. However, if the stock decreases, while catches will drop, fishing effort will fall more slowly and may even increase in an attempt

to maintain high catches, and the true fishing mortality will actually increase. As a consequence of this type of behaviour, fisheries which are affected by major environmentally caused fluctuations have a greater chance of developing into an overexploited situation.

4.2.1 Promoting a developing fishery

Provided the resources exist for developing a fishery, the manager may have to help create the proper atmosphere for fishing opportunities, whether they be prospects of employment or economic gain. The purpose is to stimulate fishing-related activities. Actions to stimulate domestic fisheries can range from advertising to providing economic incentives, or to restricting imports of fish products.

One of the frequent ways of promoting a fishery is through economic incentives which often take the form of subsidies. Direct subsidies may be guaranteed loans, reduced interest rates, tax rebates, or outright monetary awards for construction of fishing vessels and plants to process or freeze fish, or produce ice. The price paid for fish by the consumer can also be subsidised. Often the development of transportation systems, such as the construction of roads and access to markets are a sufficient stimulus to promote fisheries.

Possible indirect economic subsidies are to stimulate market conditions in an attempt to affect the demand for fish products. Examples are advertising and promotional demonstrations of product use. A government can stimulate demand by increasing institutional use of fishery products. Market competition from outside products can be reduced by increasing duties for imports. This creates a competitive advantage for domestically caught products. Licensing can also be a tool for managers to promote and stimulate a fishery. The fishermen may perceive a licence as the prospect of acquired historical rights which may stimulate their participation.

The degree and manner of promotion are, in fact, tools of the manager to be used in developing the fishery. With these tools the manager can control the orderly growth and condition of the industry. Early control and regulation of the growth phase of the fishery may be important to the success of the following phases of development. This is also the proper time to build-in safeguards to prevent the collapse of the fishery or to allow the fishing sector to survive major fluctuations in the fish resources.

Planning during this phase is essential for successful development of the fishery and to prevent or reduce risks of a collapse if the fish resources are known to vary. Usually the first attempt concentrates investments on the types of gear and equipment best suited for catching the type of fish and processing the type of product that at that moment yields the highest benefits. However, if the resources and market conditions are known to vary, this might be the best time to introduce a certain degree of flexibility in the design of vessels, gears, type of equipment, training of fishermen, etc., so as to allow easy transfer to another fishery or to alternative uses should a major and long lasting absence of the main target species, or changes in market conditions, occur. Also, at this time, the creation or strengthening of social security schemes for fishery workers should be considered.

4.2.2 Maintaining a developed fishery

Methods available to the manager during this phase of the fishery may be quite different from the ones used to promote fisheries. More often than not, they involve some form of restraint on the fishery. Also allocation among users becomes an important issue. Information on the fish stock and socio-economic state of the user groups becomes especially useful in decision-making. During this phase, the current status may be less important than the future prospects for the stocks and socio-economic conditions.

The methods available to the manager are essentially those outlined before in the biological component of management systems. Catch quotas may have to be more precisely allocated and monitored by area, time, and user group. More careful control of fishing effort as well as limited entry may have to be considered. If the growth phase is not sufficiently controlled, fleets later may have to be retired or greatly reduced. Alterna-

tive harvesting strategies based on size, sex, and condition factor of the fish may become more important. Alternative fishing activities or occupations may have to be designed in overcapitalised fisheries. Actions in reverse of those used to promote a fishery may be considered by the manager. The introduction of economic disincentives may become effective tools for managing this phase of a fishery. Methods available to control the biological component at this stage are often bogged down with too many details and special interests.

The manager must now put into practice a management system and actions that reflect wise biological uses of the resources and bring about harmony to the fishing sector. When the management fails to stop the increase in fishing effort and fishing mortality, the stock will fall to low levels of abundance either gradually or rapidly. Wise management may not always prevent a decline, but it can reduce the rate and extent of the decline, as well as its socio-economic consequences.

4.2.3 Rebuilding a depleted fishery

The manager will want to take actions different from those taken in earlier phases of a fishery. Caution may be the key. The manager may correct some previous actions since some lessons are learned during the declining phase of the fishery. For instance information may become available on the minimum abundance required for an adequate spawning biomass.

The specific methods are usually modifications of tools used to manage fisheries during promotion and maintenance stages. Some possibilities are:

- a) Closure - total ban or drastic reduction of catches to allow a higher resident biomass. The purpose is to maintain a spawning population large enough to promote rapid population growth when other conditions become right for recruitment.
- b) Creation of refuge areas - to protect remaining resident stocks or spawning refuge for the stocks.
- c) Increase fishing effort on competing species and/or natural predators - this option assumes the direct control of prey-predator relationships which may or may not be applicable from case to case. Ecosystem modelling may be useful to explore the potential impact of different alternatives of fishery exploitation.

The management approach for a preferred species at low abundance should aim at maximising the chance of recovery by allowing population size to increase to a region in the population logistic growth curve where higher yields can be expected. This is best achieved by closing the fishery and waiting for a few good year-classes to occur. Uncontrolled increases in fishing at an early stage of stock recovery are not advisable because the risk of a new collapse is high.

This phase is complicated by the multiple equilibria apparent in stock-recruitment relationships, particularly when exploitation (usually combined with adverse environmental conditions) has forced the population to a second, but lower, equilibrium as apparently happened when the Californian sardine and the Peruvian anchovy fisheries collapsed (Murphy, 1966; Csirke, 1980). While reduced exploitation still maximises the chances of recovery in a multiple equilibria system, the switch to a region of higher equilibrium depends on the occurrence of favourable environmental conditions coupled with exceptionally good year-classes, which can be an infrequent event especially if the spawning population is reduced to a very small size. For example, with the Japanese and California sardine, the reduction in fishing has not been quickly followed by recovery of the fisheries; while the depleted but still heavily exploited South African pilchard has so far displayed a degree of resilience to extinction.

In general, a management strategy which ensures a minimum spawning stock size may contribute to reducing recruitment failure and recruitment variability, thereby reducing fluctuations in overall abundance. Some knowledge of the shape of the stock-recruitment curve may be required to be able to take a management decision in this respect. Laurec and Maucorps (1981) proposed the application of decision theory when the exact shape of the stock-recruitment curve is not known.

4.3 Prescriptive vs reactive management

Management should be prescriptive and preventive rather than reactive. The historical performance of reactive management has been "too little, too late". As conditions deteriorate, managers repeatedly tend to lower their level of expectation allowing deterioration to proceed too far before action is taken. Commonly no action is taken until the resource has become economically depleted, and when action finally is taken, it is usually overly optimistic and does not restrain the fishery sufficiently to prevent its collapse.

A predetermined set of directives on how to proceed if a major symptom of adverse change in resource status should be detected should help to avoid the negative course of events of reactive management. A prescription, agreed in advance with the parties concerned (fishermen, industry, government officials, research groups, etc.), may help to eliminate elements of human psychology that may delay decisions (or their implementation) during stressful declines in a fishery. The important factors need to be considered in advance of the event, allowing optimal management to be determined objectively rather than subjectively. Thus management should develop a response programme well in advance which includes:

- a) Criteria for taking remedial action (e.g. if abundance falls below level $\underline{x}$...); and
- b) specific action to be taken (e.g. ... the fishing season will be reduced to $\underline{y}$ months).

A flowchart (Fig. 8) has been prepared to illustrate the mechanism by which the interaction between management and environment may lead to the build up of a "desired" or a "depleted" cycle in the development of a fishery. As examples, the sequence is tracked for the fishery phases diagrammed in Figures 7a and 7b, where the original decision was to develop the fishery and go from the undeveloped (1) phase to the fully developed (3) phase. The simplified diagram of Fig. 8 illustrates the possible course of events according to the six phases that describe the history of a fishery (Figs. 7a and 7b) and their corresponding cycles when management and environment interactions are considered.

In this respect it is important to note that as soon as the fishery has left the undeveloped phase (1), there will always be a risk of developing into the collapsed phase (5). However, the risk will be much lower (and the collapse less dramatic) if management is adequate. Major adverse environmental events would be needed for a fishery which is slightly developed, or one which is fully developed but well managed and monitored, to pass into a collapsed cycle, while a poorly managed fishery which has developed into an overfished situation will run into troubles much easier and faster should adverse environmental conditions occur. If a collapse is unavoidable, adequate management should favour entering into a recovery phase.

A flowchart such as the one in Fig. 8 could be used to help develop management strategies designed to rationalise exploitation of the resources, to design a response programme to major events, and to set up a system to monitor changes in the environment and resources.

4.4 Fishing strategies

Several management strategies can be considered when developing a fishery. In the biological world a wild predator faced with an oscillating resource will also oscillate in abundance with a time lag, or will migrate to a new feeding area when its food is depleted, or will switch to another more abundant prey. From the resource point of view man is also a predator, thus by analogy we can consider three broad-scale strategies which are also available to the manager. We refer to these three strategies as a fluctuating fishery, an opportunistic or migratory fishery, and a diversified fishery.

4.4.1 Fluctuating fishery

Pressures from the industry to expand during a "high pulse" in fish abundance may be justified or, even if not justified, may be too strong to put aside. Also if effort (fishing, processing, marketing, etc.) is not increased during a pulse, the extra production during a period of high abundance is lost.

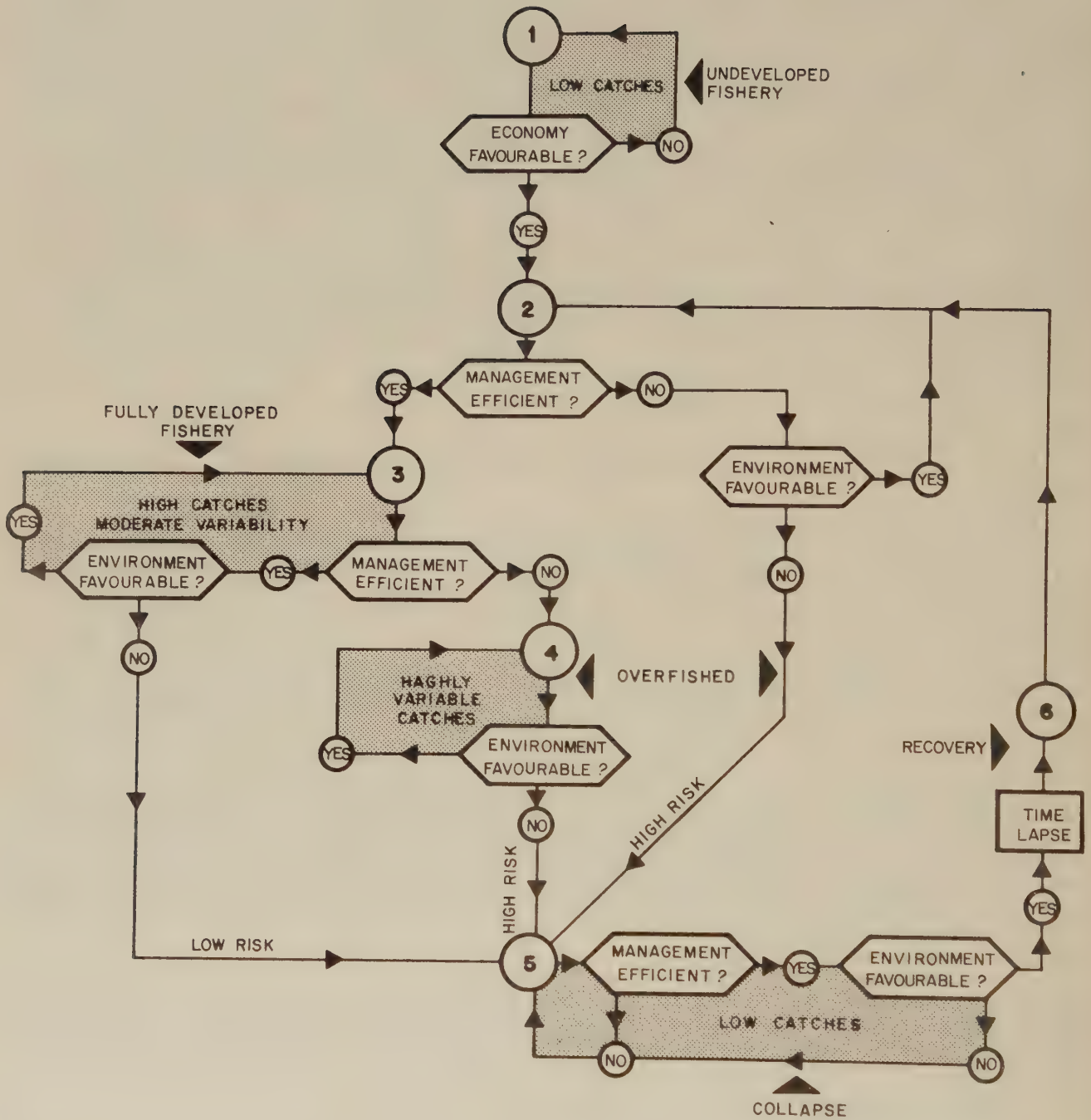


Fig. 8. Interactions between decision-making and environmental events (lozenge-shaped boxes), and the different phases in the development of a fishery (circles) described in Figure 7, as follows: (1) predevelopment, (2) growth, (3) full exploitation, (4) over-exploitation, (5) collapse, and (6) recovery.

When pulses of high or low abundance occur, the overall amount of effort (in terms of fleet capacity for instance) may be allowed to oscillate with the abundance of the resource. This should be done under control within some limits of an effort ceiling to avoid the classical overshoot of effort in excess of what the resource can stand. The difficulty here is to detect the beginning and the end of the pulse. If there is a good monitoring system and if scientists are working in the field in close collaboration with fishermen, early detection of changes in abundance may be possible. Several important symptoms of resource changes have been identified by the Working Group on Resources Study and Monitoring at this Consultation (MacCall, this volume).

The effort "ceiling" would have to be revised periodically as the data base improves or fishing efficiency changes. To ensure a proper distribution of effort and catches (among different ports, groups of fishermen, etc.) and to avoid extreme competition a system of quotas (by geographic areas, users, seasons, etc.) could be developed. Considering the risks of collapse and the importance of seasonal events, management, research and monitoring must be able to act at short notice (e.g. within a month when dealing with short-lived species). The industry and labour forces need to be prepared on the other hand to face periods of intense activity, as well as long periods of reduced fishing activity.

The best results from this strategy are obtained when the time required for an effective response is small in relation to the duration of the periods of low or high abundance. The lapse time between resource fluctuations and the fisheries' response (i.e. effort fluctuations) should be reduced to a minimum.

4.4.2 Opportunistic fishery

If a fishery is characterised by pulses or oscillations with eruptive increases in biomass, and the costs of developing a large permanent fleet to fully exploit these peaks are too high, then a fishery might have two fishing elements - a small stable element developed for periods of low biomass, and a temporary high volume element to fish the pulses or periods of high abundance.

The more stable element (to be developed on the basis of sustained, long-term production objectives) could fish with short range boats and provide catches to local factories or traditional export markets. This could be a labour intensive fishery or a highly industrialised one demanding a high investment to produce a high end-value product. Main objectives when managing this element of the fishery would be to maintain stable, even if relatively low, catches and secure market and prices.

The temporary element would be mostly concentrated in exploiting high volumes on a non-permanent basis. This temporary element could be a highly mobile fleet, most likely a foreign fleet or a fleet that can fish abroad, that would be brought in to take advantage of the high pulses. Even if the coastal state has the ability to develop its own fleet, allowing participation of a foreign fleet could still be a reasonable alternative, particularly if the possibilities of success of a local fleet are blurred by a high degree of uncertainty. A foreign fleet might be allowed to catch an "occasional surplus" and the coastal state could still capture a large part of the rent created by the "pulse" through fishing rights. The effort by this temporary fleet must be reduced drastically or transferred to another fishery as soon as the rate of increase in the stocks show the first signs of decrease. This should avoid hardships to the more stable, resident element.

A migratory fleet can conflict with local fishermen. This is most likely if primary stocks of a country are heavily fished, and if the increased effort of the foreign fleets lowers the catch rate or net rent of resident fishermen. Local fleet migrations or transfers to exploit other national stocks could be considered if some elements of the fisheries of the coastal states have still to be developed. Such transfers should be done with caution as collapse of these stocks may occur if effort is increased abruptly. Nevertheless, the overall level of effort should not be allowed to pass an ecosystem ceiling.

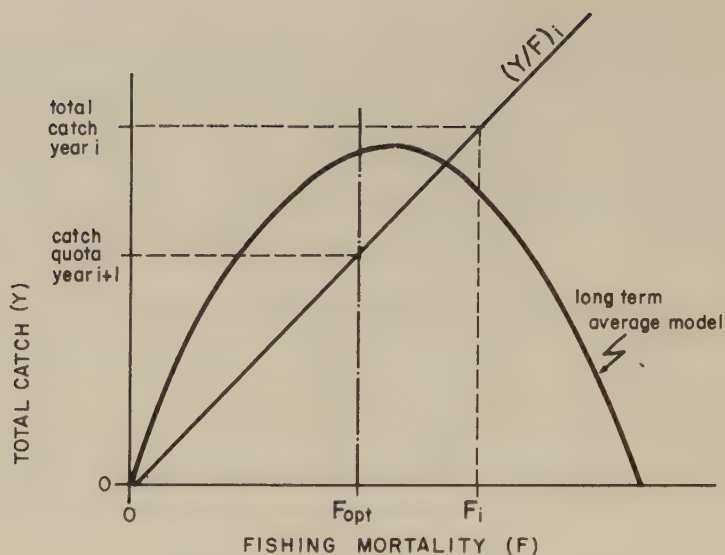


Fig. 9 Estimation of annual quota using non-equilibrium data and a constant F policy. The catch quota for year $i+1$ is estimated from the intercept of the catch-rate line (Y/F) of the previous year and the vertical line that passes through F_{opt}

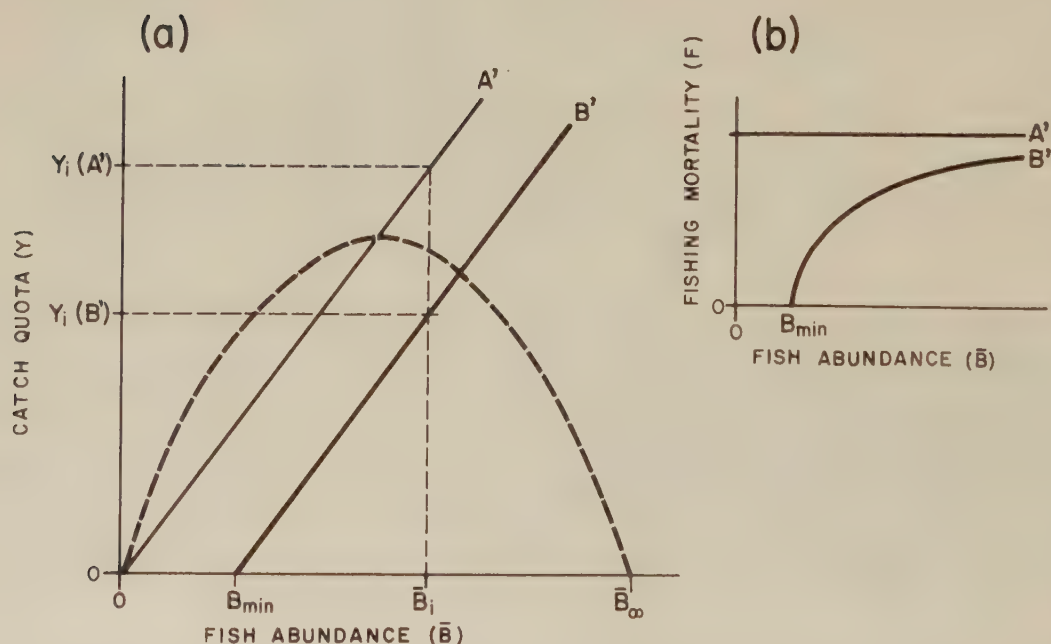


Fig. 10 (a) Estimation of annual catch quota (Y_i) using a constant F harvest policy (line A') and a variable F harvest policy (line B') when fish abundance ($\bar{B}$) is known (see text).
(b) Shows the relationship between F and $\bar{B}$ for each harvest policy

4.4.3 Diversified fishery

Fixing the maximum size of the fishery with an effort "ceiling" can be done more easily if, say, the whole array of small pelagics in the ecosystem (e.g. sardine, anchovy, mackerel plus horse mackerel, etc.) are considered as the target fish resource. The order of magnitude of harvest for the ecosystem should be estimated. Then the corresponding fishing capacity (e.g. fleet size, number of fishermen, factories, etc.) necessary for reasonably profitable operations on this ecosystem should be judged with some margin of safety. This fishing capacity will be taken as the "ceiling". A fleet established by this principle should be able to transfer its effort rapidly from one species to another during a period of increasing abundance, with little modification. A similar degree of flexibility should be built into the other sectors of the fishery.

The pelagic community of fishes is likely to be more stable than any one of its species components. The risk is that if the entire fleet concentrates on a single species with sufficient effort, the fishery on that species may collapse. The effort ceiling for the entire community may help prevent this if effort is shifted from one species to another depending on their abundances, and the natural tendency of the fleet is to switch from species of low abundance to those of high abundance. However, if there is a wide difference in value, or if there is a main target species being threatened by heavy fishing, then some additional measures may be needed. The use of species quotas (at least for the main target species) or of a system of differential taxation on landings or end products could be used to properly distribute effort among species.

4.5 Regulation of effort and catch

Any of the previously mentioned strategies imply the development at a national level of a management system to regulate fishing activities from year to year to ensure its proper distribution in time and space. In most cases this implies setting up a total allowable catch or limiting the total amount of fishing effort actually being exerted on the resource.

Traditionally, most of the strategies for regulating fishing activities have been developed on the basis of production models (Schaefer, 1954; Pella and Tomlinson, 1969; Fox, 1970), which allows calculation of the level of fishing effort that optimises yield under equilibrium conditions. Some managers and fishery commissioners also use the approach proposed by Walter (1976), which allows calculation of yearly quotas using non-equilibrium data and a constant F (fishing mortality) policy. Having calculated a long-term average model, where the optimum level of fishing (F_{opt}) has been identified, following Walter's non-equilibrium approach (Fig. 9), the catch quota for a given year is estimated from the intercept of the catch-rate line (Y/F) of the previous year and the vertical line that passes through F_{opt} .

With highly variable resources and fisheries which are more susceptible to collapse, it might be advisable to adopt a policy which tends to tighten protection of the resource at low levels of abundance and allows fishing to expand whenever fish abundance increases. This can be done in two complementary ways: first, by defining a minimum (safety) biomass level below which fishing will be banned, and secondly by ensuring that fishing mortality is reduced at a rate faster than biomass during decline periods. This can be more easily achieved by using the modified approach to production modelling originally proposed by MacCall (1980) for the Californian anchovy fishery.

This variable F harvest policy, and a constant F harvest policy, are illustrated in Fig. 10. In Fig. 10a, lines A' and B' allow calculation of a yearly quota (Y_i) for a given abundance level (B_i). Line A' , passing through the origin, implies a constant F (and presumably also constant effort) policy (see also Fig. 10b). The maximum sustainable yield (MSY) has been chosen as the long-term average objective for this example but, of course, alternative benchmarks could also be used. Line B' implies a more conservative policy, a minimum biomass level (B_{min}) is fixed (e.g. to prevent severe depletion of the resource) so that catch quotas will be reduced to zero as the average fish abundance (B) approaches this "safety" level; as this occurs F is also reduced, but at a faster rate (Fig. 10b). Also in B' , the optimum yield (and the corresponding F value) for the long-term average conditions is set at a more conservative level, below that corresponding to MSY, thus providing additional protection for the resource irrespective of its overall abundance. Here, as in the previous case, alternative benchmarks for optimum Y and F can also be used.

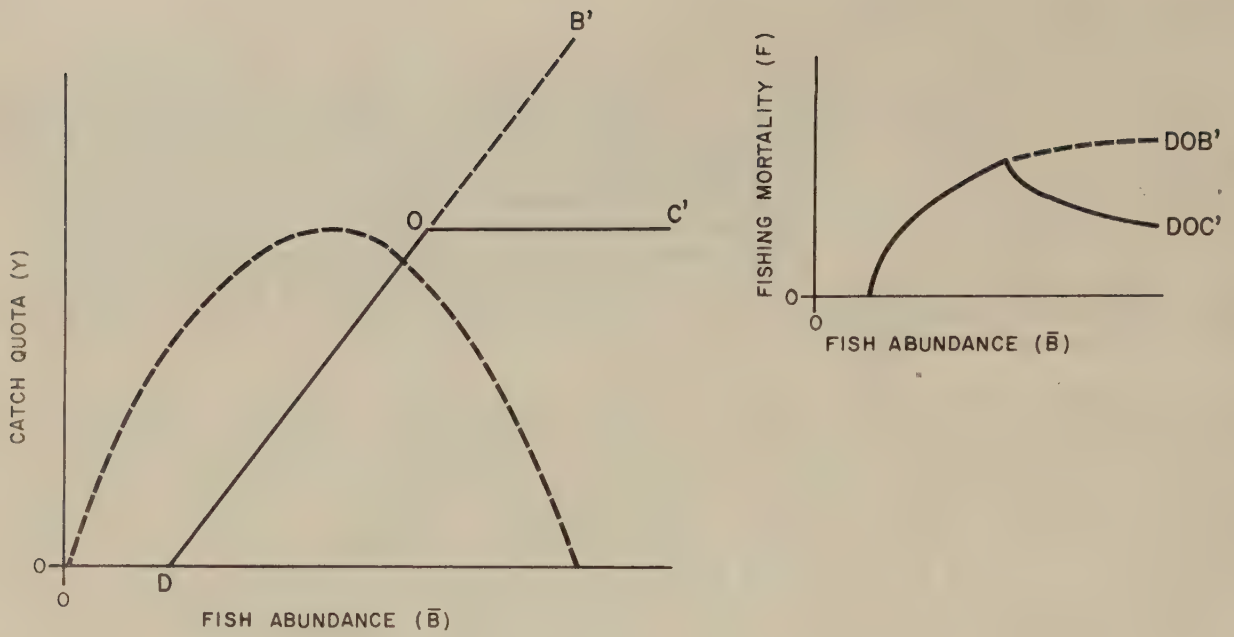


Fig. 11. Changes in the slope of the quota line (BB' and BOC') and its effect on the annual F.

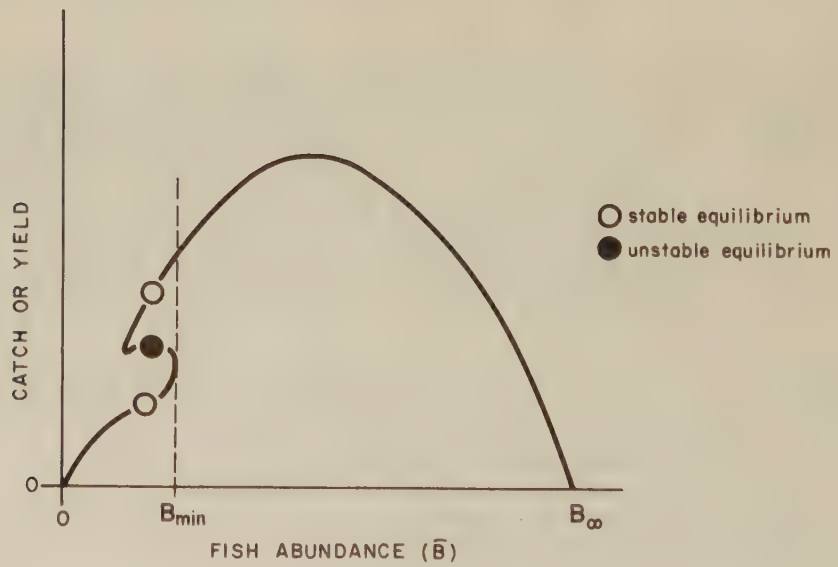


Fig. 12. Asymmetrical yield curve

The minimum biomass (e.g. for securing minimum spawning stock) can be set: (a) on the basis of historical records of stock size and recruitment success, and some knowledge of the possible stock recruitment relationship; (b) on ecological grounds (e.g. for species at the base of the food web); or (c) even arbitrarily, if no estimates of critical minimum biomass are available. Although, it is best that the level of B_{min} be agreed well in advance by all parties concerned on the basis of what each sector perceives as the minimum abundance (or catch-rate) needed to maintain a healthy fishery.

Optimum long-term average Y and F also need to be defined as early as possible for the implementation of a management strategy. Several criteria can be used to define an optimum long-term average Y and F . The best known and most quoted in technical literature is the MSY benchmark (and the corresponding F_{MSY}) proposed by Schaefer (1954) but, as pointed out by Caddy and Csirke (1983), several other benchmarks are available such as the MEY (Maximum Economic Yield) and FMEY that maximises net profits; the $F_{0.1}$ (and corresponding $YF_{0.1}$) proposed by Gulland and Boerema (1973), which takes into account the fact that in yield models the marginal yield drops significantly as the maximum yield is approached; the safer $2/3$ F_{MSY} target suggested by Doubleday (1976); and the YMBP (Yield at Maximum Biological Production) and FMBP suggested by Csirke and Caddy (1983) which supposedly maximises productivity of the stock for both man and other predators.

When the above model is used with catch-per-unit-effort (Y/f) as a measure of abundance, and catchability is suspected to increase with abundance, in order to compensate for this source of bias lines A' and B' in Fig. 10a may need to be withdrawn with reduced slopes at higher abundance levels. This approach of changing the slope of the quota line (and the corresponding F values) also suggests the possibility of implementing more complex policies. For instance, in Fig. 11, the use of the line DOC' instead of DOB' for calculating annual quotas and setting F values should have the effect of stabilising catches at high levels of abundance while providing additional buffering against resource fluctuations and overcapitalisation of the fishery. The method is robust to a poor estimate of the average production curve since it will always compensate in the right direction,

Yield models often assume that a symmetrical or nearly symmetrical yield curve exists. In reality, adverse density dependent (depensatory) effects, changes in catchability, complex species interactions, etc. will cause some asymmetry in the long-term average yield curve. Depensatory effects could even cause the yield curve to bend back in which case the yield is no longer stable, and a second stable equilibrium region could occur at lower levels of abundance (e.g. Fig. 12). Fixing a minimum biomass would introduce a correction in the right direction and will reduce the possibility of the stock shifting to a low, but stable, level of abundance.

Effort regulations are basically intended to limit the fishing mortality actually exerted on the resource and to prevent excessive overcapitalisation of the fishery sector, thus preventing it from becoming more vulnerable to collapse. Introduced changes in fishing effort (f) are usually expected to produce an equivalent change in fishing mortality; however, managers should be careful with this over-simplistic interpretation of the possible relationship between f and F . Environmental factors that so frequently affect neritic fisheries are known to alter reproduction (thus recruitment) success and overall population size while having an opposite effect on fish density (e.g. Csirke, 1980), thus altering the catchability coefficient, and the relationship between F and f . Unawareness of these changes while regulating fishing effort may lead to unexpected and often undesirable results. Close monitoring of fishing operations and of resource changes will prevent this type of situation arising.

5. CONCLUDING REMARKS

The experience gained with highly variable neritic fisheries during the last fifty years causes us to hope and believe that management strategies can be applied which produce more long-term benefits and fewer hardships than have been observed. One learns from experience and there is much to be learnt if fisheries are to provide a relatively stable, continued supply of wholesome food, gainful employment and economic benefits to the coastal states. These goals cannot be obtained by only regulating fishing effort. The environment causes dramatic changes in recruitment and overall abundance that cannot yet be forecast. Exploited fish populations interact with other biotic components of the ocean such as predators and competitors, and finally there is man who in using the resources must perhaps

be considered as the most important element of the management system. Thus there are the human, biological and physical components, all of which have to be evaluated and dealt with in a management system for highly variable fish resources, added to which there is the new recognition that high variability is a natural property of the system with which man must learn to relate.

In line with the importance of the human component, the users and their objectives must be delineated and incorporated into the management strategies. Potential conflicts between users must be recognised and minimised. This is necessary partly because they are the benefactors, but also because they influence the fishery management system and their roles must be better understood for managers to achieve the desired benefits for society as a whole.

It is important that the manager or decision-maker has the choice of several general strategies for interacting as society's central nervous system with variable fish resources. The expected period and amplitude of a pulse in the abundance of fish will alter a choice between developing a fishery with a high domestic investment and fishing effort, making use of a migratory foreign fleet to fish the pulses, or developing a fishery that can be easily displaced or shifted rapidly to alternate species as abundance varies thus maintaining some stability with a diversified fleet. The final choice, however, will also be influenced by the prevailing market conditions and other social and economical factors.

The manager has a wide range of factors to take into account but he also has a wide range of tools or methods to apply. They include the conventional tools for regulating fishing mortality, but also comprise measures that alter investment, occupational choices, and consumption of fishery products. Each tool has its place in the recognisable phases of a fishery - undeveloped, growing, developed, overfished, collapsed and recovering. Recognition of these phases and the options a manager has in each phase has the potential of maximising benefits during growth and developed phases, minimising losses during the collapsed phase, and minimising the time required for a collapsed fishery to recover.

Several management measures seem self-evident but must not be left to chance. Namely the protection of immature fish and also maintenance of a sufficient biomass during periods of low abundance to allow rapid recovery in years when environmental conditions favour high recruitment and resource expansion.

Finally, to be successful the management of highly variable fish resources must be prescriptive and preventive rather than reactive. Management should develop a response protocol well in advance that provides criteria for remedial action if abundance falls below a given level, and the remedial action must be specified.

The challenge for fisheries managers is to act, based on the experience of the last 50 years, in a manner which increases the benefits and prevents the major economic and social problems characteristic of many high variable fisheries which have experienced major collapsed periods. Keystones to such achievement are the recognition that these fisheries will vary, that environmental perturbations provide an element of risk to any strategy based on the fishery alone, that effort must be under control to increase and decrease at the proper time to obtain the benefits, and that management decisions, information systems, and government action must be prescriptive and preventive rather than only reactive.

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AGENDA AND TIMETABLE

Monday, 18 April 1983

Registration of participants
Opening ceremony

A - INTRODUCTORY SESSION

B - PRESENTATION AND DISCUSSION OF REGIONAL REVIEWS DESCRIBING
ENVIRONMENTAL AND RESOURCES CHANGES AND RELATED FISHERY RESPONSES

1. North West Pacific and Sea of Japan
2. Eastern Central Atlantic
3. South East Atlantic

Tuesday, 19 April 1983

B - PRESENTATION AND DISCUSSION OF REGIONAL REVIEWS DESCRIBING
ENVIRONMENTAL AND RESOURCES CHANGES AND RELATED FISHERY
RESPONSES (cont'd)

4. North West Atlantic
5. North East Atlantic
6. Yellow and China Seas
7. Eastern Central Pacific
8. South West Atlantic
9. South East Pacific

Wednesday, 20 April 1983

C - PRESENTATION AND DISCUSSION OF LOCALISED AND COMPARATIVE STUDIES

1. Ocean scale and regional comparisons
2. Local studies

Thursday, 21 April 1983

C - PRESENTATION AND DISCUSSION OF LOCALISED AND COMPARATIVE STUDIES

2. Local studies (cont'd)

D - PRESENTATION AND DISCUSSION OF PAPERS DEALING WITH IMPACTS OF
ENVIRONMENTAL AND RESOURCES VARIABILITY ON HUMAN COMMUNITIES

E - ROUND TABLE DISCUSSION

Informal round table discussions on objectives of fisheries
management and decision-making processes

F - PRESENTATION AND DISCUSSION OF PAPERS DEALING WITH THE APPLICATION
OF METHODS AND THEORY

Friday, 22 April 1983

F - PRESENTATION AND DISCUSSION OF PAPERS DEALING WITH THE
APPLICATION OF METHODS AND THEORY (cont'd)

G - SUMMARY AND GENERAL DISCUSSION

Monday, 25 April 1983

Morning:

H - PLENARY SESSIONS

Setting-up of four working groups, followed by presentations of
major subjects for discussion by each group

1. Presentation of major subjects for discussion by Working Group No. 1
on Resources Study and Monitoring
2. Presentation of major subjects for discussion by Working Group No. 2
on Societal Implications of Varying Fishery Resources

Afternoon:

I - SESSIONS OF THE WORKING GROUPS

1. Working Group No. 1 session, discussion
2. Working Group No. 2 session, discussion

Tuesday, 26 April 1983

Morning:

H - PLENARY SESSIONS (cont'd)

3. Presentation of major subjects for discussion by Working Group No. 3
on Environmental Studies and Monitoring
4. Presentation of major subjects for discussion by Working Group No. 4
on Fisheries Management, Implications and Interactions

Afternoon:

I - SESSIONS OF THE WORKING GROUPS (cont'd)

3. Working Group No. 3 session, discussion
4. Working Group No. 4 session, discussion

Wednesday, 27 April 1983

Morning:

I - SESSIONS OF THE WORKING GROUPS (cont'd)

5. Working Group No. 1, discussion and drafting of report
6. Working Group No. 2, discussion and drafting of report

Wednesday, 27 April 1983 (cont'd)

Afternoon:

7. Working Group No. 3, discussion and drafting of report
8. Working Group No. 4, discussion and drafting of report

Thursday, 28 April 1983

Morning:

I - SESSIONS OF THE WORKING GROUPS (cont'd)

9. Working Group No. 3, discussion and drafting of report (cont'd)
10. Working Group No. 4, discussion and drafting of report (cont'd)

Afternoon:

I - SESSIONS OF THE WORKING GROUPS (Cont'd)

11. Working Group No. 1, discussion and drafting of report (cont'd)
12. Working Group No. 2, discussion and drafting of report (cont'd)

Friday, 29 April 1983

J - GENERAL SUMMARY AND REVIEW OF THE DRAFT REPORTS OF EACH
WORKING GROUP IN PLENARY

CLOSING CEREMONY

LIST OF DOCUMENTS*

REGIONAL REVIEWS DESCRIBING ENVIRONMENTAL AND RESOURCES CHANGES AND
RELATED FISHERY RESPONSES

- Variation of pelagic fish stocks in waters around Japan (by S. Tanaka)
- Some explanation for changes in abundances of major neritic-pelagic stocks in the northwestern Pacific Ocean (by S. Hayasi)
- Stock assessment of common mackerel and Japanese sardine along the Pacific coast of Japan by spawning survey (by T. Watanabe)
- On the fisheries of Spanish mackerel (*Scomberomorus niphonius*) in the Yellow Sea and Pohai Sea (by Chan Xin Lieu)**
- The herring (*Clupea harengus pallasii*) and its fisheries in the Yellow Sea (by Chang Cheng Ye)
- On the biology and fishery of the golden sardine (*Sardinella aurita*, Val.) along southern Fujian and eastern Guangdong coastal waters (by Qiu Shuyuan (S.Y. Chiu) and Huang Tsongchion)
- Variability of pelagic fish stocks off California (by A.D. MacCall)
- Variability of the pelagic resources in the southeast Pacific (by R. Jordán)***
- Variability of the oceanographic conditions in the Ecuadorian front area (by R. Jiménez)***
- Variability in the distribution and abundance of eggs and larvae of mackerel (*Scomber japonicus peruanus*) and of some clupeoids in Ecuadorian waters (by M.L. Garcia)***
- The marine environment and fluctuations of main pelagic populations off the Peruvian coast (by S. Zuta, I. Tsukayama and R. Villanueva)***
- Changes in the abundance of pelagic resources along the Chilean coast (by J.R. Serra)
- The influence of hydroclimatic factors on the availability of the sardine (*Sardina pilchardus*, Walbaum) in the Moroccan Atlantic fishery (by H. Belvéze and K. Erzini)
- Assessment and management of pelagic stocks in the southern Benguela region (by D.S. Butterworth)
- Aspects of variability of some neritic stocks in the southern Benguela system (by J.M. Crawford, P.A. Shelton and L. Hutchings)
- Biology and availability of sardine (*Sardinella brasiliensis*, Steindachner, 1879) off the southeastern coast of Brazil (by S.A. Saccardo)***

*Unless otherwise indicated, all papers are published in full in the Proceedings of the Expert Consultation (FAO Fisheries Report No. 291, Volumes 2 and 3)

**Paper published only in abstract form in the Proceedings of the Expert Consultation

***Original title in Spanish

REGIONAL REVIEWS DESCRIBING ENVIRONMENTAL AND RESOURCES CHANGES AND
RELATED FISHERY RESPONSES (cont'd)

- The dynamics of pelagic fishery resources off the northeastern coast of the United States under conditions of extreme fishing perturbations (by B.E. Brown, V.C. Athony, E.D. Anderson, R.C. Hennemuth and K. Sherman)
- The decline in herring and mackerel and the associated increase in other species in the North Sea (by R. Jones)
- Recent history of Atlanto-Scandian herring stocks (by E. Bakken)
- On the biology and changes in exploitation and abundance of the Icelandic capelin (by H. Vilhjálmsen)

LOCALISED AND COMPARATIVE STUDIES

- Influence of the ocean on the atmospheric global circulations and short-range climatic fluctuations (by T. Tokioka)
- The role of sea surface temperature and atmospheric temperatures in the description of the thermal structure of the inversion layer (by P. Lagos)***
- Climatic change: past lessons and future prospects (by P.M. Kelly)
- Oceanographic conditions and their fluctuations in the southeastern Pacific (by O. Guillén)***
- Physics and fish populations: shelf sea fronts and fisheries (by J. Hunter and G.D. Sharp)
- Physical and biological variability in the southern region of the Chile-Peru current system (by P.A. Bernal, F.L. Robles and O. Rojas)***
- Low frequency and large-scale biological variability in the California current, 1949-1978 (by P.A. Bernal and D.B. Chelton)***
- Comparative climatology of selected environmental processes in relation to eastern boundary current pelagic fish reproduction (by R.A. Parrish, A. Bakun, D.M. Husby and C.S. Nelson)
- Species interactions in the dynamics of planktivorous fish assemblages in Lake Michigan (by J.J. Magnuson and L.B. Crowder)
- Population dynamics and factors affecting the abundance of capelin (*Mallotus villosus*) in the northwest Atlantic (by J.E. Carscadden)
- Herring and sprat: fishery independent variations in abundance (by A. Lindquist)
- Monsoon-induced seasonality in the recruitment of Philippine fishes (by D. Pauly and N.A. Navaluna)
- Spawning and larval distribution of four pelagic species and their relations to marine environmental variations off Peru (by H. Santander and R. Flores)***

***Original title in Spanish

PAPERS DEALING WITH IMPACTS OF ENVIRONMENTAL AND RESOURCES
VARIABILITY ON HUMAN COMMUNITIES

- Man, state and fisheries: an inquiry into some societal constraints that affect fisheries management (by M.H. Glantz)
- Science and decision-making in fisheries regulation (by R.J.H. Beverton)

PAPERS DEALING WITH APPLICATION OF METHODS AND THEORY

- Vertical distribution of larvae of mackerel (*Scomber scombrus*) and micro-plankton, with some conclusions on feeding conditions and survey methods (by S.H. Coombs, J.A. Lindley and C.A. Fosh)
- Population fluctuations of guano birds in the Peruvian littoral zone, 1960-1981 (by H. Tovar)***
- Batch fecundity and spawning frequency of various anchovy (genus: *Engraulis*) populations from upwelling areas and their use for spawning biomass estimates (by J. Alheit, B. Alegre, V.H. Alarcon and B. Macewicz)
- On the seasonal growth, monthly recruitment and monthly biomass of Peruvian anchoveta (*Engraulis ringens*) from 1961 to 1979 (by D. Pauly and I. Tsukayama)
- Body length variability in fish schools and cohorts: application to fisheries biology in tropical waters (by P. Fréon)
- Egg mortality of the Peruvian anchovy (*Engraulis ringens*) caused by cannibalism and predation by sardines (*Sardinops sagax*) (by H. Santander, J. Alheit, A.D. MacCall and A. Alamo)
- Comparison of egg sample probability distributions of the anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) off Peru and the anchovy (*E. mordax*) and the sardine (*Sardinops caerulea*) off California (by P.E. Smith, H. Santander and J. Alheit)
- On the variability of population biology rates: examples from the California pelagic fisheries (by R.H. Parrish and D.L. Mallicoate)**
- On the long-term changes in abiotic and biotic conditions (by A.A. Elizarov)
- Comparative study of the dynamics of a pelagic and a demersal population through a simulation model (by J. Lleonart and B. Roel)**, ***
- Production models as applied to sub-stocks depending on upwelling fluctuations (by P. Fréon)
- Why do some pelagic fishes have wide fluctuations in their numbers? - Biological basis of fluctuation from the viewpoint of evolutionary ecology (by T. Kawasaki)
- Change in abundance and species composition of neritic pelagic fish stocks in connection with larval mortality caused by cannibalism and predatory loss by carnivorous plankton (by T. Kawai and K. Isibasi)
- Variations in the parent stock and recruitment of pilchard and anchovy populations in the southern Benguela system (by P.A. Shelton and M.J. Armstrong)

**Paper published only in abstract form in the Proceedings of the Expert Consultation

***Original title in Spanish

PAPERS DEALING WITH APPLICATION OF METHODS AND THEORY (cont'd)

- Interactions of pelagic fishes and the relation between environmental factors and abundance (by B.E. Skud)
- Managing variable fishery stocks in an uncertain environment - the design of fishery management systems (by B.J. Rothschild and D.G. Heimbuch)
- Applications of a Laevastu-Larkins ecosystem model for Bering Sea ground-fish management (by Loh-Lee Low)
- Modelling fisheries: what was the question? (by G.D. Sharp, J. Csirke and S. Garcia)

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